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SUPPLEMENT TO SPONS'

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EDITED BY

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DIVISION III.

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PREFACE.

The details of engineering practice are becoming daily more and more diversified, and although many branches of the profession are almost wholly pursued by specialists, the Engineer has constantly to enlarge his sphere of knowledge to keep pace with the requirements of the age.

At the present time, science and its applications seem to go onward almost together. No sooner is a new fact announced than it is made available for some useful purpose; and never was there an age so fertile in discoveries as that in which we live. They may be thought to be of a minor kind; and we cannot perhaps hope that any discovery yet remains to be made of such importance and vital interest, as to work out a revolution in our industrial relations equivalent to that effected by the steam engine. We must expect rather to go on eking out and completing the fabric of our knowledge by the acquisition of absent details, and by arranging and harmonizing its parts, strengthening evidence and cancelling error, thus rendering the elements more and more intelligible, serviceable, and of readier access to the practical man.

To aid in some measure the Engineer's professional labours, was the object of Spons' 'Dictionary of Engineering,' and the success which has attended its publication has been a gratifying proof of its appreciation by those for whose use it was intended.

As the book has now been some years before the public without addition or revision, there are many subjects of importance which, of necessity, are either not included in its pages, or have been treated less fully than their present importance demands. With the object, therefore, of remedying these omissions, this Supplement has been prepared. Each subject has been treated in a comprehensive way, but of course without repeating the information already included in the body of the work.

Such articles as those upon Air Compressors; Belting; Blasting; Brakes; Bridges; Chimneys; Electrical Engineering; Explosives; Gearing; Iron; Lights, Buoys, and Beacons; Machine Tools; Mining Machinery; Railway Rolling Stock; Rock Drills; Sanitary Engineering; Shafting, and the like, are treatises that may be sought for in vain in the technical text-books.

It is a pleasing task to render thanks to those whose labours have so materially aided in the compilation of this Supplement. Their names are all duly recorded on the following page.

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121, Bishopsgate Street Within,
London, May 1st, 1881.

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TABLE IV.—SPRING B.

Original length	46·9 mm.
Final length	46·85 „
Set per cent. of maximum compression	0·29
Length after 3 mm. extension	46·82 mm.
Mean compression a kilogramme	0·97 „

Load Kilos.	Compression Millimetres.	Compression a Kilo.	Difference from Mean.		Difference from Final.	
			Absolute.	Per Cent.	Absolute.	Per Cent.
I.	II.	III.	IV.	V.	VI.	VII.
1·5	1·53	1·02	+·05	5·2	+·07	7·4
4·5	4·38	0·97	·00	0·0	+·02	2·1
9·0	8·60	0·96	−·01	1·0	+·01	1·1
13·5	12·90	0·96	−·01	1·0	+·01	1·1
18·0	17·11	0·95	−·02	2·0	·00	0·0

TABLE V.—SPRING C_1.

Original length	46·25 mm.
Final length	46·19 „
Set per cent. of maximum compression	0·45
Length after 3 mm. extension	46·22 mm.
Mean compression a kilogramme	0·85 „

I.	II.	III.	IV.	V.	VI.	VII.
1·5	1·49	0·99	+·14	17·6	+·22	28·6
4·5	3·91	0·87	+·02	2·4	+·10	13·0
9·0	7·33	0·81	−·04	4·7	+·04	5·2
13·5	10·62	0·79	−·06	7·0	+·02	2·6
17·5	13·43	0·77	−·08	9·4	·00	0·0

TABLE VI.—SPRING C_2.

Original length	43·42 mm.
Final length	43·36 „
Set per cent. of maximum compression	0·42
Length after 4 mm. extension	43·39 mm.
Mean compression a kilogramme	1·64 „

I.	II.	III.	IV.	V.	VI.	VII.
0·75	1·31	1·75	+·11	6·7	+·19	12·2
3·00	4·93	1·64	·00	0·0	+·08	5·1
6·00	9·73	1·62	−·02	1·2	+·06	3·8
9·00	14·01	1·56	−·08	4·9	·00	0·0

TABLE VII.—SPRING D_1.

Original length	37·25 mm.
Final length	37·13 „
Set per cent. of maximum compression	0·75
Length after 2 mm. extension	37·23 mm.
Mean compression a kilogramme	0·53 „

I.	II.	III.	IV.	V.	VI.	VII.
1·5	0·87	0·58	+·05	9·4	+·07	13·7
4·5	2·57	0·57	+·04	7·6	+·06	11·8
9·0	4·97	0·55	+·02	3·8	+·04	7·8
13·5	7·14	0·53	·00	0·0	+·02	3·9
18·0	9·35	0·52	−·01	1·9	+·01	1·9
22·5	11·49	0·51	−·02	3·8	·00	0·0
27·0	13·68	0·51	−·02	3·8	·00	0·0
31·5	16·04	0·51	−·02	3·8	·00	0·0

TABLE VIII.—SPRING D$_2$.

Original length	38·85 mm.
Final length	38·84 „
Set per cent. of maximum compression	0·06
Length after 4 mm. extension	38·89 mm.
Mean compression a kilogramme	1·50 „

Load Kilos.	Compression Millimetres.	Compression a Kilo.	Difference from Mean.		Difference from Final.	
			Absolute.	Per Cent.	Absolute.	Per Cent.
I.	II.	III.	IV.	V.	VI.	VII.
0·75	0·99	1·32	—·18	12·0	—·25	15·9
3·00	4·49	1·50	·00	0·0	—·07	4·5
6·00	9·34	1·56	+·06	4·0	—·01	0·6
9·00	14·15	1·57	+·07	4·6	·00	0·0

TABLE IX.—SPRING E.

Original length	43·02 mm.
Final length	42·64 „
Set per cent. of maximum compression	2·2
Length after 3 mm. extension	42·82 mm.
Mean compression a kilogramme	0·98 „

I.	II.	III.	IV.	V.	VI.	VII.
1·5	1·53	1·02	+·04	4·1	+·06	6·2
4·5	4·40	0·98	·00	0·0	+·02	2·1
9·0	8·74	0·97	—·01	1·0	+·01	1·0
13·5	13·20	0·98	·00	0·0	+·02	2·1
18·0	17·31	0·96	—·02	2·0	·00	0·0

In Tables II. to IX. the final length is the distance between the marks after all the weights have been removed, and the difference between that and the original length, is the set which the spring took in the operation. Column I. of the Table gives the total load in kilogrammes, including the pin and scale, put on the spring, and Column II. gives the compression caused by that load. Column III. is the compression a kilogramme. The mean compression a kilogramme stated above each table is obtained by plotting the figures of Columns I. and III., greatly exaggerating the compressions, and measuring the area thus obtained with a planimeter. In Berndt's Tables the arithmetical mean of Column III. is taken as a sufficiently near approximation. In the majority of cases the two first places of decimals agree; in none is the difference considerable.

Column IV. gives the difference between the compression a kilo. at each load and the mean compression a kilo. for all the loads obtained as above, and Column V. gives the value of this difference as a percentage of the mean compression a kilo. Column VI. gives similarly the difference between the compression a kilo. at each load and that at the maximum load, Column VII. giving this difference as a percentage of the compression a kilo. at the maximum load.

None of the springs returned completely to their original condition after removal of the load. In one case, D$_2$, the set was as little as 0·06 per cent. of the maximum compression of the spring; in one, E, as much as 2·2 per cent. of the same quantity. In the mean, however, it is only 0·64 per cent. The mean absolute value of the set is about a tenth of a millimetre, and its effect on an indicator card, allowing for the increased stroke as in Table I., would be very nearly $\frac{1}{75}$th of an inch. With the well-used spring E the set would appear on the scale of the diagram as about $\frac{1}{20}$th of an inch.

The conclusions as to the elasticity of the springs which can be drawn from their behaviour under gradually increasing loads are, however, much more important than these. In no case does the resistance of the spring to equal increments of pressure remain even approximately constant throughout its range. In every instance except one, the spring D$_2$, as will be seen by an examination of Column III., the resistance to compression is, as might be supposed, less at small than at large pressures. The mean resistance is equal to the actual resistance at a point which varies from a fourth to a third of the maximum pressure, so that the compression is more uniform at higher than at lower pressures. The eight springs tested, the average condition of which seems certainly to have been better than the condition of the springs which we commonly use in practice, show the following results;—

Table X.—Averages.

	Per cent.
Average variation of compression a kilo. at $\frac{1}{12}$th of maximum pressure from mean compression a kilo.	7·7
Average variation of compression a kilo. at $\frac{1}{4}$th of maximum pressure from mean compression a kilo., about	1·6
Average variation of compression a kilo. at maximum pressure from mean compression a kilo.	4·2
Average variation of compression a kilo. at $\frac{1}{12}$th of maximum pressure from compression a kilo at maximum pressure	13·1
Average variation of compression a kilo. at $\frac{1}{4}$th of maximum pressure from compression a kilo. at maximum pressure, about	6·5
Average variation of compression a kilo. at $\frac{1}{2}$ of maximum pressure from compression a kilo. at maximum pressure, about	2·8

If therefore, the indications of these springs were read on a scale corresponding to their mean compression a kilo., there would be a probable error of over 4 per cent. at full pressures, and of nearly 8 per cent. at very low pressures, and special experiment would be required to show whether the error was + or —, as is shown by the behaviour of the spring D_2, Table VIII. If a scale were used, on the other hand, corresponding to the final compression a kilo., rather than to the mean, the probable error at full pressures would be very small, the mean error at half-pressure being only 2·8 per cent., and diminishing rapidly from that point to the maximum. At low pressures the error of such a scale would be much greater than that of the other, as Table X. shows.

It must be borne in mind that the errors so far considered, are of quantities which correspond only to the ordinates and not to the areas of indicator cards. If we suppose, for example, that we could obtain an indicator diagram with ordinates corresponding to the measured compressions of C_2, Table VI., then if there were no expansion, and the back pressure line coincided with that of the atmosphere, so that the diagram was simply a rectangle, the error of area would be exactly the same as the error of height, or 4·9 per cent. if measured with the mean compression scale, and 0·0 per cent. if measured with the final compression scale. But if there were expansion, so that the upper line of the card varied in height, each pressure would have its own error, and the area of the whole figure would have an error somewhere between that of the greatest and that of the least ordinate. It is quite conceivable that the pressure might fall far enough, and the shape of the diagram be such, that the errors of excess in one part of the card exactly balanced those of defect in the other. The mean pressure and the horse-power deduced from such a card might, therefore, be exactly right if measured by a mean compression scale, while the actual measured pressures might be very far wrong at all points of the stroke except one.

In the second series of experiments undertaken by Berndt, the springs were heated by a jet of steam of a little over atmospheric pressure until a thermometer placed in the spring indicated 90° C., 194° F. In other respects they were the same as the experiments already described, with the addition of springs F and G.

The results are summarized in Table XI. The length of the spring is first recorded, both cold and hot. These lengths do not in all cases correspond with the lengths given in the former Tables, as it was found necessary to re-mark some of the springs. The third line of Table XI. gives the length under the maximum load, the maximum compression being the difference between the mean loads applied. The fourth and fifth lines of the same Table record the effect on some of the springs, of removing and reapplying the maximum load two or three times, and also of setting the spring gently in vibration, while the maximum load was resting on it. The sixth and seventh lines show the final length of the spring, still kept hot, when the weights were removed, after it had been a little stretched by hand in the way formerly mentioned. The eighth line shows, lastly, the observed lengths of the springs after they had become cold.

Looking even at the springs least used, and otherwise in the best condition—as B, for instance—the set is quite appreciable. In the case of C_1 and D_1 the maximum load was removed and reapplied, without shock, two or three times, and in both instances the compression was very notably increased thereby. The springs C_1, C_2, D_2, and E were set in vibration very carefully, when under their maximum load, and always, it will be seen, with the same result, the increased compression being very marked in every case. With some of the springs the same operation was also carried on at smaller loads, and always with a perceptible increase of compression, the alteration being naturally, however, less marked with the smaller pressures.

The first part of Table XII. will enable a comparison to be made between the compression of the springs cold and hot. The mean compression a kilogramme is distinctly, but not very greatly, different in the two cases, the hot springs having sometimes a greater and sometimes a less mean compression. The behaviour of the heated springs under load was exceedingly irregular. The greatest compression a kilogramme was at the least load in A_1, A_2, B_1, C_1, and C_2, and at or near the greatest load in D_1, D_2, and E, while in most of the springs the changes in compression at medium loads seemed to follow no law whatever.

The results of Berndt's experiments, up to this point, cannot be applied directly to the springs when working in the indicator cylinders. Their value lies in giving some idea of how far such springs as have been ordinarily used in practice, are really in themselves elastic, and how far their elasticity is impaired by use.

TABLE XI.

Lengths given in Millimetres.	Springs.									
	A_1.	A_2.	B.	C_1.	C_2.	D_1.	D_2.	E.	F.	G.
1. Original length, cold	45·31	47·24	46·87	46·25	43 39	37·20	38·88	41·15	..	..
2. „ hot	45·36	47·29	46·87	46·30	43·41	37·20	38·93	41·26	49·74	47·58
3. Length under maximum load, hot	30·09	29·49	29·02	32·68	28·46	20·78	24·50	23·83	31·38	29·70
4. Length after several removals and reapplications of maximum load, hot	..	..	..	32·37	..	20·24	..	..	..	..
5. Length after being several times set in vibration under maximum load, hot	..	..	..	32·01	28·26	..	24·13	23·56	..	..
6. Final length after a few millimetres extension, hot	45·28	..	46·79	..	..	36·32	..	..	..	..
7. Final length after such extension repeated twenty times, hot ..	..	..	..	45·91	43·38	..	38·77	41·01	..	..
8. Final length, cold	45·24	47·17	46·74	45·93	..	36·35	..	..	..	..

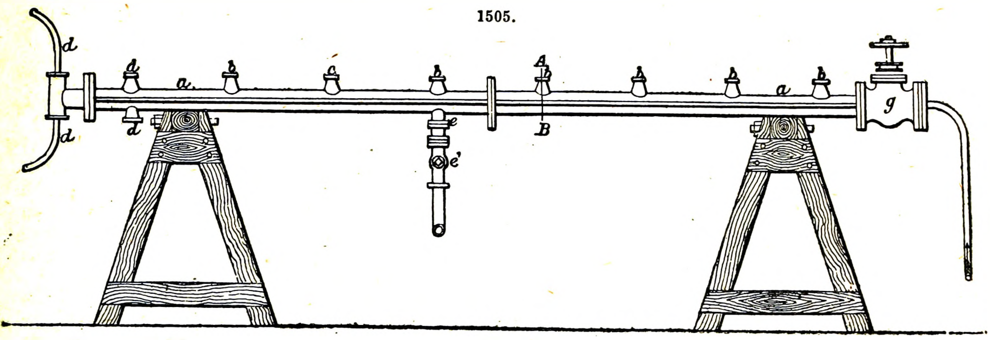
The experiments show the compression of the springs with certain loads placed directly upon them, and the relation between the compressions and the loads. We know the diameter of the indicator cylinder in each case, and the ratio in which the compression of the spring is increased by the parallel motion; these were all carefully measured, and the results have already been given in Table I. We are, therefore, able to calculate the scale of the diagram for each spring in its own indicator, neglecting piston friction, leakage, and the like. The question arises, how does this scale agree with the scales provided by the makers for the spring, and therefore, universally used with it? For the sake of more easy comparison, we have reduced all the scales to pounds per inch, like those we are in the habit of using. Under the double line in Table XII. these scales are given both for the mean and the final compressions of the springs, and for both cold and hot experiments. Beneath these is given the scale supplied by the makers for each spring, and at the bottom of the Table the percentage of difference between the actual scales for the free springs and the scale commonly used for the same springs in the indicator. As an illustration of the meaning of the figures. If we took spring C_2 cold, and put its maximum load, 9 kilogrammes, upon it, we should find it to be compressed 14·01 mm., or 1·56 mm. a kilogramme. Calculating from the dimensions of indicator C_2 given in Table VI., we find that this corresponds to a diagram scale of 19·6 lb. an inch, that is, that the pencil would move through 1 in. for every 19·6 lb. pressure a square inch in the cylinder.

TABLE XII.

Compressions given in Millimetres.		Springs.									
		A_1.	A_2.	B.	C_1.	C_2.	D_1.	D_2.	E.	F.	G.
Mean compression a kilogramme, springs cold		0·89	1·79	0·97	0·85	1·64	0·53	1·50	0·98	—	—
„ „ „ hot		0·90	1·78	1·00	0·84	1·67	0·51	1·59	0·98	—	—
Difference per cent. of former		+1·1	−0·6	+3·0	−1·2	+1·8	−3·8	+6·0	0·0	—	—
Final compression a kilogramme, springs cold		0·84	1·73	0·95	0·77	1·56	0·51	1·57	0·96	—	—
„ „ „ hot		0·85	1·75	0·99	0·78	1·66	0·54	1·60	0·96	1·22	1·19
Difference per cent. of former		+1·2	+1·2	+4·1	+1·3	+6·4	+5·9	+1·9	0·0	—	—
Scale for indicator cards, pounds an inch, corresponding to:	Mean compression cold ..	39·1	19·4	29·1	36·0	18·6	68·9	24·3	35·4	—	—
	„ „ hot ..	38·6	19·5	28·2	36·4	18·3	71·6	22·9	35·4	—	—
	Final „ cold ..	41·4	20·0	29·7	39·7	19·6	71·6	23·2	36·2	—	—
	„ „ hot ..	40·9	19·8	28·5	39·2	18·4	67·6	22·8	36·2	22·7	23·7
Scale supplied with spring, lb. an inch ..		44·26	22·13	30·0	45·1	20·7	..	22·13	44·28	24·0	24·0
Difference between actual scale and scale supplied, in per cent. of the former:	Mean compression cold ..	13·2	14·1	3·1	25·3	11·3	..	−8·9	25·0	—	—
	„ „ hot ..	14·6	13·5	6·4	23·9	12·9	..	−0·3	25·0	—	—
	Final compression cold ..	6·9	10·6	1·0	13·6	5·6	..	−4·7	22·3	—	—
	„ „ hot ..	8·2	11·8	5·2	15·1	12·5	..	−0·3	22·3	5·7	1·2

The apparatus used in the experiments upon the springs in their indicators is shown in Figs. 1505 and 1506. The boiler was below ground, so that the pipe from it to the apparatus could slope always upwards. This pipe is seen at the right of Fig. 1505. It communicates through a stop valve *g*, with a couple of cast-iron tubes *a a* of 40 mm. internal diameter, bolted together and supported horizontally on trestles. On these tubes are a number of branches, one of which is shown in section on a larger scale in Fig. 1506. Those marked *b b*, which are about 16 in. apart, were used for the Richards indicators, the indicator cock being screwed into the hole in the cap shown in Fig. 1506. The branch *c* is for the connection to the mercury gauge, and the branches *d d* were used with the Ashton-Storey indicators. Longitudinal flanges *f f* cast upon the tubes *a a* served for the attachment of boards, Fig. 1506, in a convenient position for placing note-books upon. The branch *e* and the cock e^1 served to clear the tube of water if necessary. The syphon mercury gauge was used for determining the steam pressure.

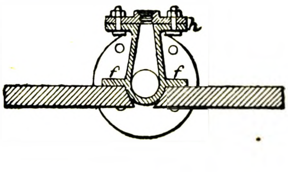
1505.



The experiments were conducted by three observers, one at the indicator and two reading the mercury gauge. On communication being made with the boiler, the cock e^1, Fig. 1505, was left open until only pure steam issued from it before the experiments began. The readings of the gauge were made always on a signal being given by the observer at the indicator. The observations made were in essential points as follows; their order was of course varied in different cases, and the whole series of observations were not made with every one of the springs. In the first place a horizontal line was drawn on the card by a pin fixed for the purpose to the frame of the indicator. This line served as an axis from which the various ordinates could be measured; it was repeatedly checked, to make sure that the paper had not shifted on the drum. Before the admission of steam, and while the instrument was still cold, an atmospheric line was drawn. The piston rod was then gently raised by hand, and then left free to take up its own position, which seldom coincided exactly with the former position. The spring was next depressed by hand in the same way, and again left free, and again in most cases it did not return quite to its former position. This raising and depression by hand were generally repeated once or twice. Steam was then admitted to the apparatus, and when the indicator cylinder had become fairly heated the same experiments were repeated. These experiments may be called deflection experiments. The height of the mean atmospheric line, which will be afterwards referred to as that from which pressure ordinates were measured, was taken as the arithmetical mean of the observed heights, after upward and downward deflection.

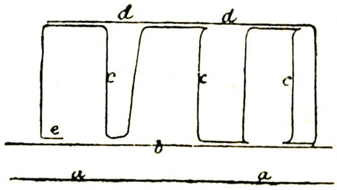
Steam was next admitted to the cylinder, and after a few seconds' pause, so as to allow the spring to take up its full compression, the pencil was brought to the paper, and a first pressure line marked by moving the latter over it. The pencil was then raised and depressed as before, a fresh line being marked each time, and the height of the mean pressure line was taken as the arithmetical mean of the heights of all these deflection lines.

1506.



The distance between the mean pressure line for any pressure, and the mean atmospheric line, was taken as the mean ordinate for that pressure, corresponding to the particular spring and indicator used in the experiments.

In taking an indicator diagram no time is allowed for the spring to take its full compression against the frictional resistance in the cylinder, and against what may perhaps be called the molecular inertia in the spring; it therefore appeared necessary to make some experiments with conditions more exactly representing those under which an indicator card is taken in practice. To do this the indicator cock was opened and closed quickly several times in succession, while the drum cord was pulled by hand, the pencil, therefore, tracing on the paper diagrams Fig. 1507, resembling the admission portion of common cards, and produced under identical conditions, at least so far as the motion of the indicator pencil was concerned. Before allowing the pencil to leave the paper, it was in many instances allowed to trace a final pressure line along the whole card, the indicator cock standing open. An atmospheric line was drawn on each card both before and after the diagram was drawn, in the one case with a pencil previously at rest, in the other, of course, with a pencil which had just been in motion, downwards, as the pressure was removed.



1507.

While the admission line of an indicator diagram is being traced, the momentum of the moving parts tends to increase the height of the pencil, the friction in the cylinder tends to diminish it, but during the tracing of the expansion curve the latter action is reversed. The resistance and the imperfect elasticity of the spring still tend to hinder motion, but the motion hindered is downward instead of upward, so that the height of the pencil is at each instant greater than it would be were the action of the apparatus perfect. Just at the cut-off the pressure begins to fall before the pencil does, the latter will only move when the difference between the steam pressure and the downward thrust of the spring has become equal to the resistances due to the causes just mentioned. That some action of this kind must take place is obvious enough, but whether or not to an injurious extent could only be determined by experiment. For this purpose the pipe *a*, Fig. 1505, was left for some time in free communication with the boiler, all the indicator cocks being at the same time open. The steam pressure in the boiler was gradually lowered, and the indicator pistons allowed simply to follow it. The pencil was not left in contact with the paper, but at intervals a short pressure line was marked.

The nature of the diagram experiments may perhaps be made clearer by Fig. 1507. The results of the other experiments hardly need illustration. Fig. 1507 is a copy of one of the diagrams taken with spring E. In the figure, *a* is the fixed horizontal, *b* the first atmospheric line, and *c c c* the diagram. It will be seen that the cock was opened and closed quickly three times in succession, and then allowed to remain open while the paper returned, the pencil then tracing the final pressure line *d*. Communication being again opened with the atmosphere the final atmospheric line *e* was drawn.

In Table XIII. the first column gives the reference number of the springs, and the second the diagram scales supplied with them, in pounds a sq. in. an inch. The latter are repeated here for the sake of convenience. No scale was supplied for D_1. Column 3 gives the approximate steam pressure at which the experiments were made. It is necessary that this be known in each case, because the error of the springs differs at different pressures. Columns 4 to 11 of Table XIII. give, in a form comparable with the figures of column 2, the diagram scales corresponding to the different lines drawn. The numerals I., II., in Roman type, refer to the first and second series of experiments respectively. The scales deduced from the first pressure lines are given in columns 4 and 5, from the arithmetical means of the upward and downward deflections in column II., and from the moving pressure lines in columns 7 and 8. These different lines for one experiment with one spring were illustrated in Fig. 1507. The scales for the free springs, that is the springs out of their indicators, at or near the pressures of column 3, are given in columns 9, 10, and 11, so that some estimate may be made of the total effect of piston friction on the springs.

TABLE XIII.

Spring.	Scale supplied with Spring.	Pressure (approximate) of Experiment.	Diagram Scales in lb. a sq. in. an inch, deduced from							
			First Pressure Lines.		Mean Height of Deflection Experiments.	Moving Pressure Lines.		Free Springs.		
								Cold.	Hot.	Hot.
		lb. a sq. in.	I.	II.	II.	I.	II.	I.	I.	II.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
A_1	44·3	61	41·1	42·3	41·1	42·0	42·8	40·4	39·5	40·5
A_2	22·1	25	22·5	..	..	22·9	..	..	..	..
B	30·0	60	29·5*	28·6	28·6	29·5*	28·9	29·4	28·5	28·6
B	30·0	40	..	29·1	29·0	..	29·4	29·4	28·7	28·6
C_1	45·1	64	46·2†	46·3	42·5	39·2†	46·4	38·6	38·7	38·7
C_1	45·1	42	..	42·0	38·0	..	42·6	37·7	37·7	37·4
D_1	..	64	..	68·2	67·7	..	68·3	69·0	71·6	70·2
D_1	..	41	76·9	..	..	82·5	..	66·0	70·0	68·8
D_2	22·1	26	25·8	..	..	26·2	..	..	..	..
E	44·3	60	..	36·8	34·8	..	36·9	35·5	35·8	33·5
E	44·3	43	38·1	37·3	35·3	38·4	37·9	35·7	35·1	34·5
F	24·0	60	23·6	..	..	24·3	..	..	22·7	..
G	24·0	59	23·9	..	..	23·9	..	..	23·7	..

* At a pressure of 69 lb. a sq. in. † At a pressure of 59 lb. a sq. in.

Comparing columns 4 to 11 among themselves we find very large discrepancies in the cases of C_1 and D_1, discrepancies so large as to make the differences in the other cases appear almost trifling, although in some instances they are not inconsiderable. If we compare these columns, however, with column 3, we find that in A_1, C_1, D_2, and E there are very notable differences, the scale supplied only representing in the roughest way the real compression of the spring.

Table XIV. contains a summary of results. The first column gives the reference letter for the spring, and the second the condition as to the boiler pressure, rising or falling, under which the experiments were carried on. In the third column are noted the approximate, maximum and minimum pressures, and the fourth gives the number of readings taken as the pressure changed from one to the other. The results of the experiments are given in the two last columns. Column 5 gives the average error of the readings in pounds a sq. in., as compared with the scale supplied with the instrument, and column 6 the average difference between the rising and falling reading for any pressure between those given in column 3. With the exception of the rising pressures of spring C_1, the errors given in column 5 are all positive, that is, errors of excess, but in all cases the excess is much greater for falling than for rising pressures. Had the quantities in column 5 been compared, however, with the scale of the free spring, the rising and falling errors would in all cases, except D_1, have been of opposite signs, the reading on the scale supplied being always in excess of the true reading, as Table XIII. shows for the springs treated in Table XIV. The importance of the differences shown in column 6 lies in this, that the expansion line of an ordinary indicator card, and often the admission line also, where there is wire drawing, is traced under circumstances very much resembling those under which the falling pressure lines were here drawn, the mischief being only aggravated by the fact, that in drawing the card the pencil remains throughout in contact with the paper, while here pencil friction was not allowed to act.

Table XIV.

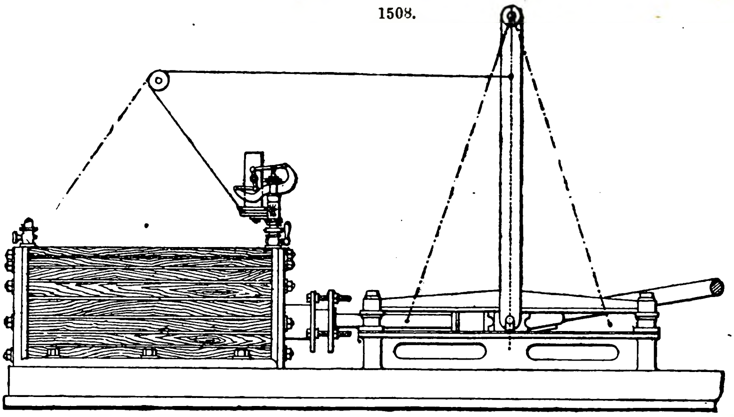
Spring.	Pressure in Boiler.	Pressures between which Readings were taken.	Number of Readings made.	Average Error of Readings compared with Scale supplied with Spring.	Average Difference between Readings at Rising and Falling Pressures.
1.	2.	3.	4.	5.	6.
		lb. a sq. in.		lb. a sq. in.	lb. a sq. in.
A_1	Rising	38 and 70	6	+ 2·4	3·5
A_1	Falling	70 ,, 20	5	+ 5·9	
B	Rising	36 ,, 68	6	+ 1·1	3·3
B	Falling	68 ,, 19	5	+ 4·4	
C_1	Rising	36 ,, 68	6	− 3·6	11·4
C_1	Falling	68 ,, 19	5	+ 7·8	
D_1	Rising	34 ,, 68	6	+ 5·3*	4·2
D_1	Falling	68 ,, 19	5	+ 9·5	
E	Rising	34 ,, 68	6	+11·6	12·5
E	Falling	68 ,, 19	5	+24·1	
F	Rising	38 ,, 56	4	+ 1·4	1·9
F	Falling	56 ,, 22	3	+ 3·3	

* Compared with scale of free spring (hot) at maximum compression.

From the differences which are constantly found in the length of indicator cards, taken under precisely similar conditions, we know that the string has stretched somewhat, under the pull due to the resistance of the paper drum spring. The stretching of the cord, which is in this way apparent, must no doubt take place to a different extent at different parts of the stroke. At the beginning of the stroke the cord must be most stretched, the paper drum lagging behind, as it were, the point from which reciprocating motion is taken. At the end of its stroke the cord has probably recovered its original length, so that during the latter part of the stroke the drum has been gaining on the point mentioned. The result is that to get a true diagram from the actual card, we should have to shift the earlier ordinates forward, and the later ones backward, one ordinate only remaining fixed, the one, namely, which corresponds to the point at which the driving point and the paper drum had equal velocities. In order to determine quantitatively the value of the correction to be made in the indicator card on account of string stretching, Berndt made a number of experiments with a special and very ingenious apparatus devised by Weinhold. In this apparatus a reciprocating bar was driven by a crank, and motion given to the indicator cylinder by a cord attached to the bar. An electric connection was arranged by which pieces of paper attached to the bar and the cylinder, respectively, could be simultaneously pierced by an electric spark a certain number of times, at regular intervals during each stroke. In this way it became easily possible to make a very accurate comparison between the motions of the drum and the driving point. The relation in which they stood to each other, was found to be as just described, the unchanged ordinate coming, in the average of all the experiments, to 0·78 of the stroke. Berndt estimated the effect of the alteration by drawing ideal diagrams for cut-off at 0·5 and 0·3 of the stroke, correcting them for each experiment, and then measuring the alteration of area by a planimeter. For both catgut and good hempen cord tried in several ordinary conditions as to dryness, he found that the necessary correction amounted only to 0·5 per cent. The cord was 4·3 ft. long and was carried straight from the bar to the drum, without guiding pulleys. No perceptible alteration was found in one set of experiments in which the cord was 7·0 ft. long, similarly arranged. The use of thin brass wire, 7 ft. long, reduced the error to 0·3 per cent. With cord or wire, 7 ft. long, carried over two guide pulleys at intervals, the error came out equal, and was 0·9 per cent. With very wet cord it was found that the error was much increased, as might be expected; it was 1·8 and 3·6 per cent. respectively in two experiments. The error was in defect in every case, so that the indicator cards were too small by the fraction mentioned. It will be seen that on the whole this error may be neglected when good and dry cord is used, and the length is not too great; it seems seldom likely to reach 1 per cent. with the cuts-off examined by Berndt. For earlier cuts-off, however, it must be greater, although in the absence of detail we cannot say by how much. The error in the form of the expansion curve caused by the stretching of the string will necessarily be much more perceptible than the error of area, and may be quite noticeable even when the latter is unimportant.

For making the connection to drive an indicator the beam engine offers excellent facilities, for it is only necessary to tie the string upon one or other of the radius rods, to obtain an adjustable length of stroke, which can be readily suited to the length of indicator diagram required. In horizontal engines, the usual practice is to fix a temporary wooden radius bar, Fig. 1508, to oscillate upon a centre, and its lower end has a fork or slot to work at any convenient part of the crosshead.

1508.



The point of suspension in such cases must be perpendicular to the centre of the stroke, and the indicator string should be taken over a pulley, set at right angles to the radius bar in its middle position, and at such a level as to be opposite the part where the oscillations measure a convenient stroke for the particular indicator employed. In the case of high-speed horizontal engines, the slot arrangement, if not well constructed, is liable to produce an unsatisfactory vibration at the ends of the stroke, and thus affect the diagram by causing unaccountable irregularities therein. For use with such engines, it is well to have a short connecting link between the motion block and the end of the temporary radius bar, instead of a slot, and care must also be taken to have the wooden bar itself tolerably stiff, so as not to bend with the rapid motion it encounters.

In setting indicators upon cylinders, it must be borne in mind that where a rapid current of steam occurs, as in ports and pipes, any orifice at right angles to the direction of the current receives less than the real pressure, consequently erroneous diagrams will be taken whenever steam passes rapidly across the orifice of the indicator cock, and thus it must never be fixed in the ports or near them. Before fixing any indicator, its permanent stop-cock must be opened for several revolutions of the engine, to clear away foreign matter that is sure to accumulate therein. When engines are indicated for the first time, this precaution is more especially necessary. String for driving the indicator should not be used quite new, as it continually stretches; and where any great length has to be employed, fine brass wire is preferable. In order to regulate the length of cord correctly a slip noose is found very useful. This consists of a piece of leather about $1\frac{3}{4}$ in. long by 2 in. wide, and $\frac{3}{16}$ in. thick. Three fine holes are perforated through this leather, and a piece of cord about 2 ft. long, tied to one end. The other end of the string, after passing through the remaining two holes, has a hook attached, and a ring may be conveniently placed on the opposite loop. This arrangement forms a sort of slip noose, and is very convenient for lengthening or shortening the indicator string.

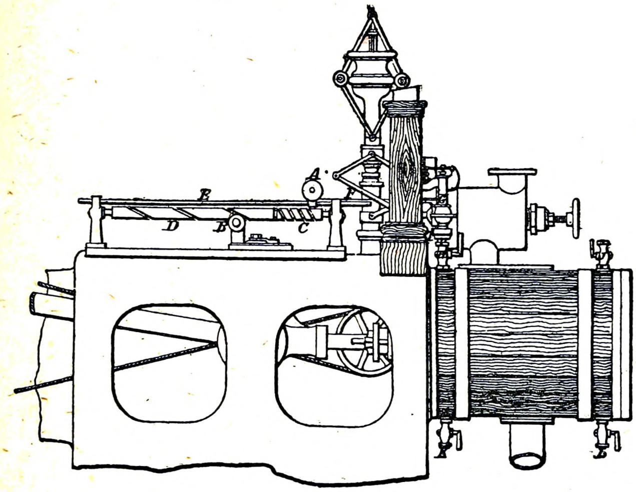
Where practicable, it will be found the best plan to employ two indicators for each cylinder with the connecting pipes as short as possible, the common plan of using pipes joining the two ends of a cylinder with a three-way cock to a single indicator, is open to considerable objection, and in any case the steam passage should be as short and direct as possible, and of ample area, in order that the pressures in the engine and indicator cylinders may coincide to the nearest possible limit.

Fig 1509 is of an arrangement for giving motion to the indicator, due to G. Cawley. The motion is reduced by two screws having different pitches, or a pitch ratio $= \frac{L}{l}$, where L = the stroke of the piston, and l = stroke of indicator cord in the same unit of measure. It can be demonstrated that providing the screws D and C have a non-varying pitch, or one of similar variation, the motion of the bobbin A is reduced from the motion of the crosshead guide B with absolute correctness.

The screw reducing arrangement and the cocks H and I are fixtures on the engine, and are, therefore, always in readiness for taking a diagram. A is a friction-bobbin and finger-wheel firmly attached to the sliding rod E. On the bobbin is wound the cord F, giving motion to the indicator, and its length can be adjusted by simply turning the finger-wheel. The friction of the bobbin must be sufficient, to prevent it being unwound by the pull due to the spring in the indicator and barrel. B is a movable tongue or nut working into the screw D, and can be put in or out of gear by turning the circular bolt-head. When a diagram is about to be taken, the tongue B is allowed to spring into gear with the screw D; and the indicator thus receives a reduced piston motion from the bobbin A.

The arrangement, Fig. 1508, is troublesome at high speeds, and that Fig. 1510 may then be employed, here a vibrating lath is attached to a short arm set at B; if, for instance, a cord is to be taken in the direction B C, or at C for the direction C D, it will then, however, be necessary to take several measurements, and to prepare a diagram showing the direction of the cord, in order to get the correct position of the pin, and for two different positions of the indicator to have two cords and two pins. If, however, a segment of a circle is bolted on to the lath with a broad groove turned on the edge, and the cord secured at the end, it can be led away in any direction, and will always leave the circle at the right point.

1509.



1510.

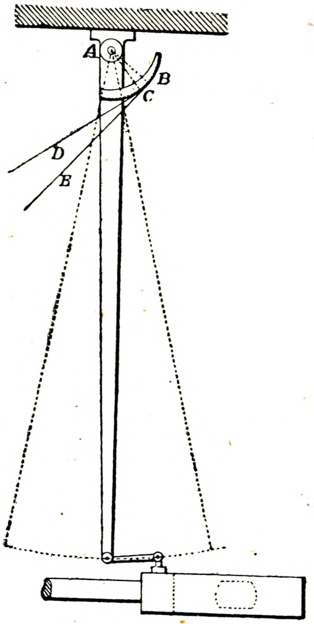
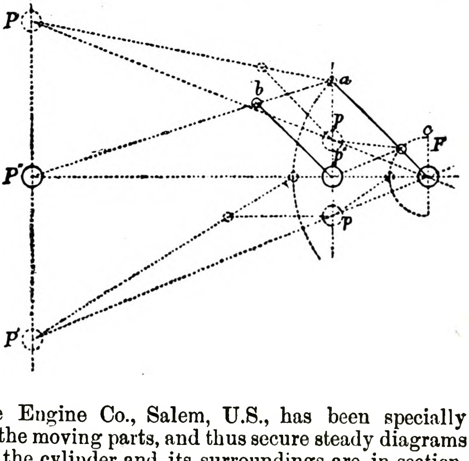


Fig. 1511 illustrates a mode of reducing the stroke of the engine correctly and conveniently by the use of the pantagraph. In Fig. 1511, if in the straight line P'' F, P'' represents a point in the piston-rod head or guide-block, p'' a point in which motion of the paper drum is taken, P P′ the stroke of the engine, $p\,p'$ the stroke of the indicator, and F a fixed point or centre, $\frac{\text{P P}'}{p\,p'} = \frac{\text{P}''\,\text{F}}{p''\,\text{F}}$. Take any convenient angle as P'' a F, and from the point p'' draw $p''\,b$ and $p''\,c$ parallel to F a and P'' a. Then P'' a, a F, $p''\,b$, and $p''\,c$ will represent the links of a pantagraph, jointed together at b, a, c, p'', and if the point P'' is moved in the straight line P P′ the point p'' will move in the straight line $p\,p'$ parallel to P P′ and $\frac{\text{PP}'}{a\,p'} = \frac{\text{P}''\,\text{F}}{p''\,\text{F}}$.

So long as a straight line passes through the points P'', p'', and F, the position of the link $p''\,c$, or that of $p''\,b$, may be varied at pleasure; for example, the link $p''\,b$ might be continued through b, and the link F a continued through a, and the link $p''\,c$ made to fall on the other side of $b\,a$, but $p''\,c$ must always be parallel to $b\,a$, and $p''\,b$ to $c\,a$.

The advantages given by the use of this motion are; That the motion of the piston may be reduced without error of any kind; and the fulcrum F may be shifted to any position, in the same plane with the links, near F, without producing any other effect than moving the point p'' in a corresponding direction, which position may be easily determined from the ratio $\frac{\text{P}''\,\text{F}}{p''\,\text{F}}$ for P'', p'' F will always lie in the same straight line, and the motion of P'', when the point F is fixed, will be always exactly copied in the given ratio by the point p''.

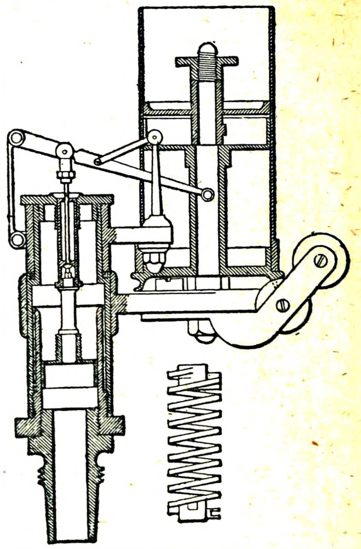
1511.



Thompson's indicator, made by the Buckeye Engine Co., Salem, U.S., has been specially designed to reduce as far as possible the weight of the moving parts, and thus secure steady diagrams at high speed. In Fig. 1512 of this instrument the cylinder and its surroundings are in section, as well as the paper drum and the parts which carry it, but the two systems are cut on a different plane, that of the paper barrel being beyond the other, though the two planes are parallel. The stem of the working piston is short and has a hollow trunk screwed on it, inside of which the connecting rod works. This rod has on its lower end a head or collar, the upper surface of which forms part of a sphere, while the lower is concave and concentric with the upper. An internal collar in the trunk fits the spherical surface of the head on the connecting rod, while a stud which is screwed into the stem of the piston, has a hemispherical end which fits the concave surface of the head. This stud can be adjusted out or in, to take up lost motion at any time, or make the joint free as may be required.

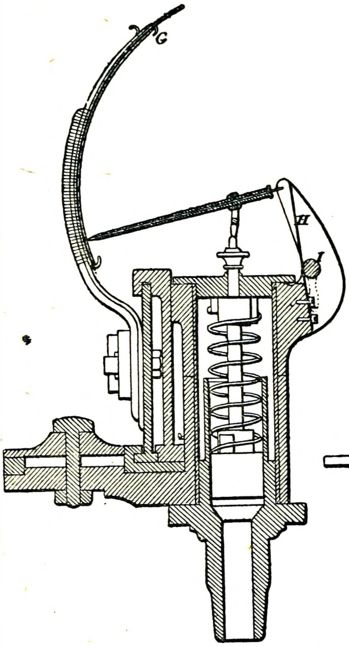
This joint, being universal, allows the lateral vibration required for the parallel movement, as well as acting as a swivel, to allow the head piece which carries the lever and parallel device to swing round, and carry the marking point to or from the paper. The lever E which carries the pencil is pivoted to a swinging bracket, while the link or radius bar, being pivoted to the fixed standard, controls the movement of E, so that the pencil moves in a straight line, that result being secured by the arrangement of the several pivots and a proper length for the radius bar. The pivots are all made with taper steel pins and must work free. The spring, Fig. 1513, when in place, works between the piston and cap and is fitted to screw on. The connecting rod is screwed into the head and locker by a keeper nut, which allows the connection to be shortened or lengthened, to accommodate slight variations in the length of the springs, or to throw the pencil higher or lower on the paper according to the pressure or vacuum existing. The spring of the paper drum, which is not shown, is contained in the drum, and its ends are hooked on to studs, one of which is on the inner periphery of the drum, and the other on the boss of a milled edge flange, so that by turning the flange the tension of the spring can be properly adjusted, a thumb nut then holding it in position. The thread in this nut is made right or left according to the hand of the instrument, it being made so that the force of the spring will tighten it. The other parts are almost identical with those of the Richards indicator illustrated at p. 2017 of this Dictionary.

1512.

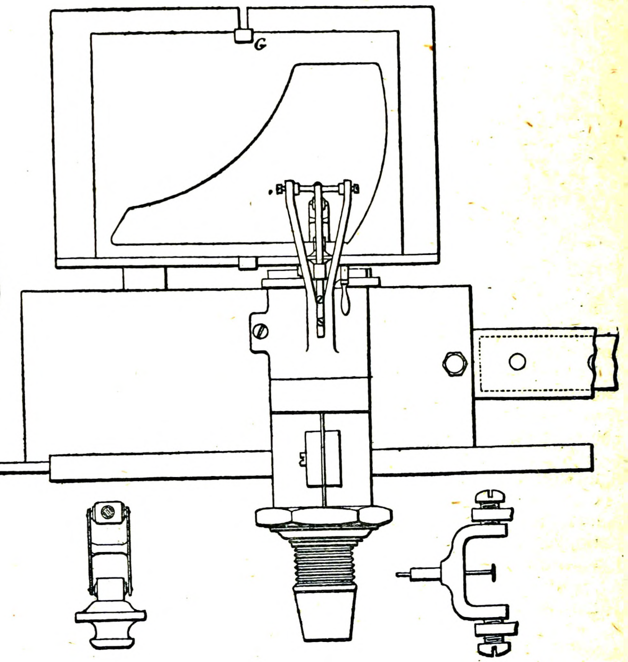


1513.

1514.



1515.



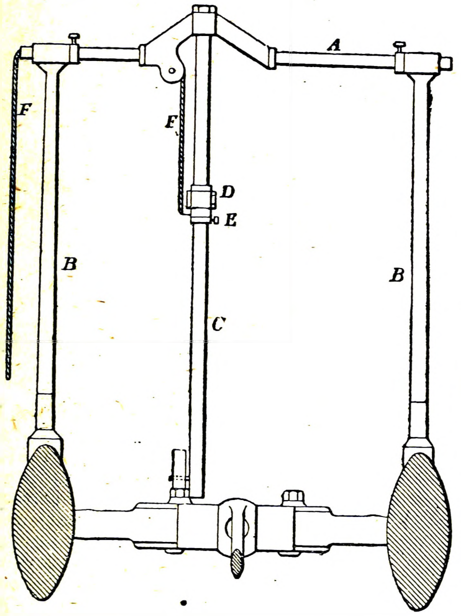
1516.

1517.

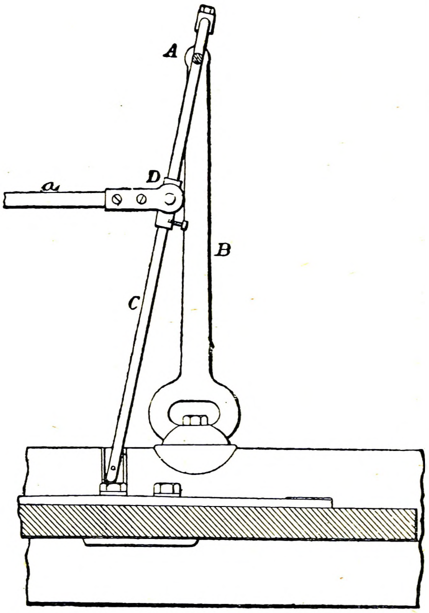
In the indicator devised by John E. Sweet, Figs. 1514 to 1517 the parallel motion is dispensed with, and a uniform travel obtained with both piston and pencil point.

Figs. 1518 and 1519 show the reducing device adopted by John E. Sweet for giving motion to the paper. A, Fig. 1518, is a bent rock-shaft mounted in bearings over the crosshead of the engine, in the supports B B. C, a pendulum rod swung back and forth by the motion of the crosshead; this carries a sliding block D, which can be raised to the top of the rod or allowed to fall to any desired point by the adjusting collar E. A string F, passing through the centre of the rock-shaft and over the pulley, enables the operator to raise or lower this block, regardless of the speed of the engine. The trunnions on the block are at rest when the block is raised, so their axis corresponds with the axis of the rock-shaft, and have a motion proportional to the motion of the crosshead when let down. A weight is suspended somewhat heavier than the block and its connections to the cord, so that by raising the weight motion is imparted to the indicator, whilst dropping the weight stops it. This arrangement would need modifying to suit circumstances, but the principle of sliding the block to and from the axis of motion is applicable in all cases. In the place of a string for connecting the reducing device with the indicator, a connecting rod, one end of which is shown at *a*, Fig. 1519, may be used.

1518.



1519.



Figs. 1514 to 1517 show Sweet's indicator in cross-section and elevation.

The principal feature is in the method of holding and moving the paper. Instead of wrapping it round the outside of a cylinder, it is bent and held on the inner surface of a segment; and instead of being moved around and back in a circle, it is moved forward and back in a straight line. So the power from the engine is carried directly to the paper-holder, without strings or springs, and is a positive motion which can be run at any speed. By this method of fixing the paper it can be placed in one-fourth the time, and any kind of paper or card can be used. To place the card it is only necessary to set the lower edge in the bottom channel, press it back, and hook the hook G over the upper edge.

The pencil arm is a tube of about $\frac{1}{16}$ in. external diameter, through the centre of which passes the marking point, of copper wire, about $\frac{1}{32}$ in. in size. The pressure is put on the marking point by the spring H, which is forced against it by the cam I. In this way the pressure is put on, and the force is the force of the spring, entirely beyond the control of the operator.

The pencil has a range of 60°, but, instead of moving 30° above and 30° below, the arm plays from $7\frac{1}{2}$° below to $52\frac{1}{2}$° above the horizontal, and the link placed in that inclined position that gives to the pencil so nearly a perfectly uniform velocity ratio that when multiplied twelve-fold the variation is scarcely discernible. It will be seen that it not only dispenses with the parallel motion, but does away with considerable weight in the pencil and pencil-holder at the end of the arm, where it does the most harm.

It is stated that with this indicator as good cards have been obtained at 330 revolutions as from Richards at 220 or from the Thompson at 270, under the same conditions.

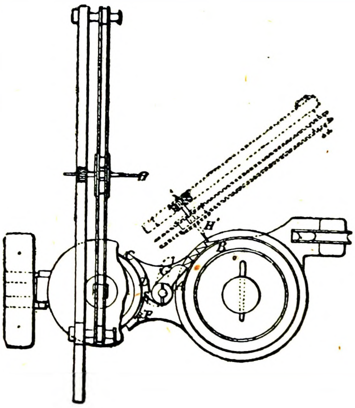
Fig. 1520 is of Darke's detent, fitted to Richards' indicators by Elliott Bros., of London. This contrivance is arranged to control the motion of the paper drum of the indicator without the inconvenience of hooking and unhooking the cord.

The Fig. 1520 represents an indicator in plan, with detent attached. C D is a small segment of brass pinned on the lower end of the ferrule which carries the pencil arms, and which therefore moves with any motion of them. The end D engages the nose of the pawl A, which again engages a segment of a ratchet wheel B. A small spring F presses upon a pin in the pawl at G, and tends to keep it in gear with the ratchet segment.

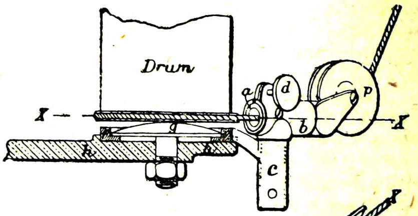
The indicator is shown with the paper drum at the end of its stroke, and the spring of the drum consequently in tension, the cord being supposed to be in connection with the moving engine. With every stroke of the engine the cord is therefore tightened and slackened, the slack being taken up with a little elastic placed in the cord, between the engine and the eye of the cord of the paper drum.

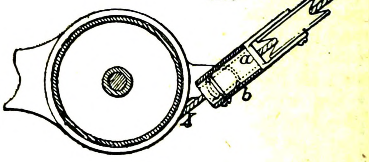
When a diagram is about to be taken, the pencil arm is moved to the position shown, and the end of the brass segment C D gently presses the nose of the pawl A at D; as the cord tightens by the motion of the engine, the pressure given by the spring of the paper drum upon the tooth of the ratchet B is removed, the pencil advances immediately towards H, the pawl takes the position as shown dotted, and the paper drum commences its movements with perfect smoothness. To stop, it is only necessary to move the pencil arm by a backward motion, when the pawl again engages the ratchet and prevents the return stroke. It will be seen that so long as the nose of the pawl rides upon the brass segment C D, the indicator retains, and can be used in, its old form.

1520.



1521.





1522.

The contrivance is one which will be found very useful, especially when taking cards from fast-running engines, or under circumstance which render the card difficult of access for hooking and unhooking in the ordinary way.

Stanek, of Prague, has proposed a new arrangement, Figs. 1521 and 1522, of a guiding pulley for the cord which moves the paper drum of an indicator. It will be seen that the pulley *p* can be turned round an axis X X, whereas the cord, passing through the hollow pivot *a*, remains in its proper position. By means of the screw *d* the pulley can be fixed in any position required.

In comparing this arrangement with that usually employed, it will be found that the cord can be moved more freely in any direction, without interfering with the correct action of the apparatus. Moreover, the arrangement, if once properly adjusted, is not liable to allow the cord to double on the paper drum pulley, that is to say, to go round more than once, a case which is by no means uncommon with the ordinary pulleys.

Continuous indicators give a permanent record of power employed, and one of the contrivances of this description is Ashton and Storey's steam-power meter, of which the essential details are represented by Fig. 1523.

This instrument measures the power given out at every stroke, like any other indicator; and it multiplies the varying pressures by the speed, and records the amount by means of figured dials attached to the apparatus. Thus, if the amount of power indicated yesterday be deducted from that shown to-day, the exact power expended in the interval is known with perfect accuracy.

The indicator piston A has a connection with the upper and lower side of the cylinder by pipes attached to cocks *a* and *b*, so that the exact difference of pressure on the two sides of the engine piston, are transferred to the indicator piston to draw it up or down, and compress or extend the spring E, which is calibrated to each linear inch for any desired scale of pounds a square inch. A long pinion B, with its integrating wheel D, is carried by the indicator piston rod; it is free to turn round, but held endways by collars. A circular disc F, mounted upon a short horizontal shaft, is held by a light spring against D, and this disc has an oscillation given to it for a suitable connection with the engine.

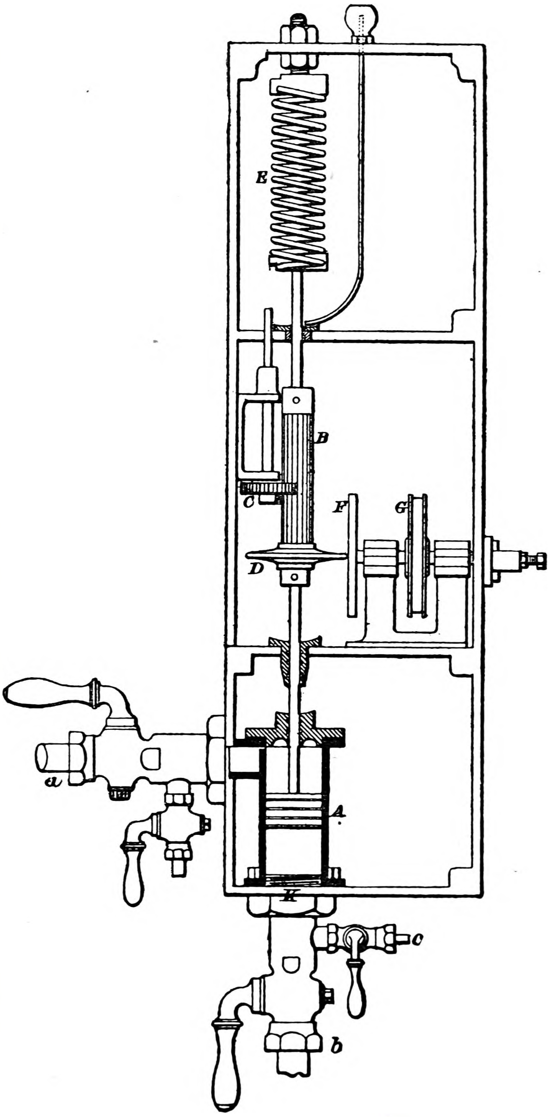
The integrating wheel D is set to stand at the middle of the disc F when all is at rest, and there is no pressure on either side of the piston, so that in the position shown no motion of F has any effect on D. But as steam pressure forces D upwards or downwards, the movement of F is transferred to D, and the extent of motion so given to the index during any stroke of the engine, is proportionate to the pressure of the steam on the indicator piston during that stroke, because the rate at which the integrating wheel D is driven by the disc F, is directly proportionate to the distance by which it is raised or lowered from the centre of the disc, and this distance is the same as the amount of compression or extension of the indicator spring.

When the stroke is finished, and a return stroke commences, the disc will rotate in the opposite direction; and as the steam acts on the opposite side of the piston, when the motion of the engine's piston is reversed, the integrating wheel will be moved to the opposite side of the centre of the disc, and both it and the index will continue to be moved in the same direction as before; the quantity of motion through the return stroke of the engine will again be proportionate to the pressure of the steam on the piston, and will be added to the movement of the index during the preceding stroke. By this means, therefore, the registering index is moved during each stroke of the engine, through a space proportionate to the sum of the moments of pressure exerted during that stroke, and consequently the total amount of power developed during any given time is thus indicated.

In these instruments, as generally made, the proportions of the moving parts and gearing for reducing the motion down to the registering index are so arranged that each unit on the dial represents 1000 foot-pounds a circular inch of the engine piston; but for convenience of reference, where the indicator is intended to be employed constantly upon any particular engine, a separate index may be provided on the dial, for showing at once the load on the engine in horse-power, by simply observing the movement recorded by this special index during one minute.

In Kenyon's pistonless indicator a tube similar to that of a Bourdon gauge is utilized to transmit the pressure, but there are many objections to this form, and it is doubtful whether the tube can stand excessive pressure without damage.

1523.



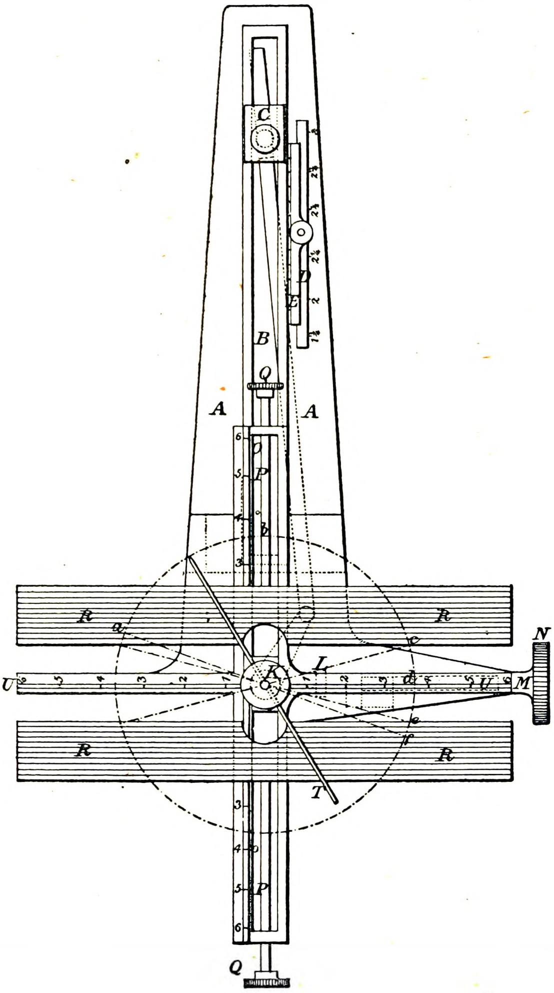
A slide valve indicator is employed to show the whole of the motion and action of a slide valve, and at the same time duly allow for the variations due to any length of connecting rods, thus furnishing a ready means of quickly comparing one valve with another, or obtaining the whole of the particulars which show the distribution of the steam in any existing engine.

Fig. 1524 is a plan of Wm. Cooper's slide valve indicator, as made by Elliott Bros., and Fig. 1525 is a side elevation. A A is the frame carrying the moving parts. B is a long slot in which slides the slide block C corresponding to the piston of an ordinary engine. D is a small slot parallel with the long slot B and graduated on one side, giving various lengths of connecting rod relative to the length of the stroke. E is an adjustable graduated scale, on which may be read off the various positions of the slide block C, either on the up or down stroke. F is a swivel coupling for fixing any length of connecting rod in relation to the stroke of the engine. G is the connecting rod. H is a crank-pin for giving motion to the connecting rod, it is fixed to the bevel wheel J. K is a centre stud carrying the bevel wheel J; and L is a pinion gearing into and driving the bevel wheel and crank. M is the pinion shaft worked by the milled wheel N which operates the whole instrument. O O is a centre slot in which are placed two rods P P, and worked by the knobs Q Q. R R are traverse sliding plates, to indicate the lap and lead of the valve, they are also worked by Q Q, which are connected with the sliding blocks S S. T is a sliding pointer, adjustable in length by the small screw V, and fixed to turn with the crank; it may be set at any angle to the crank by the milled nut X. U U are two arms graduated in inches for adjusting the length of the pointer T, which is usually set to describe a circle whose diameter equals the travel of the valve.

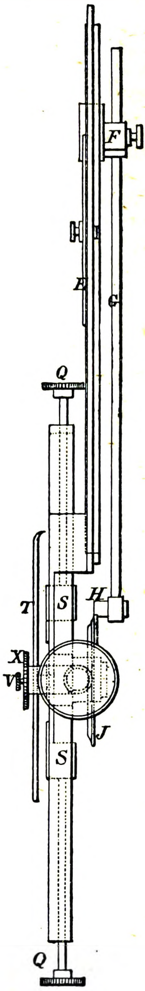
To use the instrument the crank is turned on to the centre, and the scale E adjusted to the required length of connecting rod by bringing the top of the scale opposite the proper length of rod, the set screw at F is then eased, and the piston adjusted to the zero on the scale E. The zero on this scale is either at the top or bottom, as the crank is either on the top or bottom centre, and E is doubly marked, reading both up or down as the case may require. The two plates R R are moved from the central, a distance equal to the lap of the valve. If we suppose the crank to be on the bottom centre then the pointer T is moved across U U, set to half the travel of the valve, and fixed by the central screw V; the bent point is turned up towards the piston until it crosses the first edge of the lead plate R, such a distance as will equal the lead required, and fixed there by the milled nut X. The point of the needle, *a*, now actually becomes the centre of an eccentric, and its position with regard to the crank is the same.

The instrument is then ready for use. By turning the wheel N, the needle moves from its position towards the top of the circle which it describes. When it reaches *b* the valve is full open and the distance from R to end of the needle is the opening the port then has. When the needle reaches the edges of the plate R at *c*, the valve is closed, and when, by continuing the motion, the needle reaches the centre line U U at *d*, the exhaust, if the valve has neither inside lead nor lap, begins on one side, and compression on the other. Again, when the needle reaches *e* compression ceases and lead begins, before the crank is on the centre. Finishing the stroke by turning the wheel a little further, and inserting the pin on the right to ensure the crank's proper position; the needle will then be at *f*, and the distance from *f* to the edge *e* will be the lead the valve has at the other end. Continuing the motion for the other stroke, and at each of the points above named, the position of the piston with regard to the scale E is to be read off.

1524.



1525.



The instrument affords the means of ascertaining how far the piston has travelled when the steam port is full open, and how much this opening varies by using the reversing link as a means of expansion; as also the part of the stroke where the steam is cut off by the valve closing, and expansion begins, as well as the point at which expansion ceases by the opening of the steam port to the exhaust. It will in addition indicate the portion of the stroke performed under the expansion of the steam; the point at which the exhaust ceases and expansion begins; the portion of the stroke performed during the compression of the steam; the point where the steam port is opened by lead and before the piston has finished its stroke; the portion of the stroke performed against the steam which is admitted by lead; and also how these details differ between the up and down stroke, owing to the angles formed by the connecting rod.

IRON.

In the smelting of iron the advisability of roasting iron ore before reduction in the blast furnace has long been a debated subject. Some ores no doubt benefit materially by this preparation, and it is a common practicew ith many ironmasters to employ this preliminary treatment of the mineral. F. Akermann, the celebrated Swedish metallurgist, has thoroughly investigated the matter, and from his researches we abstract the particulars which follow.

The action of roasting iron ore is in many cases simply mechanical, hard ores become brittle and can then be better worked. Ores containing carbonate of lime should not be roasted long before reduction, as the caustic lime produced in the roasting slakes on exposure to the air, absorbing moisture and carbonic acid, and producing a considerable amount of dust.

The heat required for roasting ores containing carbonic acid and water is considerable. The heat which becomes latent on the evaporation of water is 536, and according to Regnault each unit of water which is raised from t to t' degrees and evaporated at the latter temperature requires $606 \cdot 5 + 0 \cdot 305\,t' - t$ units of heat. To the considerable amount of heat which is bound in roasting ores containing hygroscopic water we must add that which is required to expel the water of hydration from its chemical combination with the oxide of iron; we possess at present no data to calculate the amount of this loss.

For the decomposition of each unit of carbonate of lime Favre and Silbermann calculate 373·5 units of heat, that is $373 \cdot 5 \times 100 : 44 = 849$ calories for each unit of carbonic acid expelled from the carbonate of lime, or $373 \cdot 5 \times 100 : 56 = 667$ calories to each unit of weight of causticized lime. The absorption of heat due to the decomposition of the carbonate of iron is not known, but as the protoxide of iron is a much weaker base than lime, it may be assumed that it is less than that given above for lime.

The decomposition of carbonate of lime begins at about 600° C.; but it is not till nearly 900° C. that it takes place at all rapidly, and even at this temperature a lump of limestone requires a long time to become caustic in its interior. For driving out carbonic acid from finely divided carbonate of iron, only 300°–400° C. are necessary, and the water contained in pulverized bog iron ore is expelled at 200°–300° C. The temperature necessary for driving out the water and carbonic acid from the hydrates and carbonates of iron is therefore not very high; but much heat is absorbed during the operation, and still more in causticizing the lime.

Some iron ores do not require roasting. This is the case with those which contain no sulphur and which are, in their natural state, sufficiently loose in texture to allow the reducing gases of the blast furnace to penetrate. Some of the softer varieties of hæmatite may at once be tipped into the blast furnace in their natural state; but if the hæmatite be very compact, a moderate red heat will be found to break it up into smaller pieces, thus giving better access to the gases. Some of these ores, however, are liable to fall into dust if roasted at a low temperature; in such a case a higher temperature must be used. In some cases, when the ores contain constituents which are expelled by heat, it is not necessary to roast them specially, the volatile substances being expelled in the upper part of the blast furnace itself. With high furnaces the amount of heat bound in this operation does not interfere with the reduction of the metal. Many hydrated ores are very difficult to roast, on account of their fine state of subdivision, and if they are heated during the operation to a temperature sufficient to clinker them, they become more difficult of reduction in the blast furnace. There is also a considerable loss of ore, which is carried off in the state of a fine dust by the gaseous products of combustion. In some cases carbonated ores are smelted direct without previous roasting; but experience has taught that it is more advantageous to roast them slightly first. This is no doubt partly due to the temperature required to drive out the carbonic acid being higher than that necessary for the evaporation of the water in hydrated ores. The reducing zone in the blast furnace is driven lower down in consequence, with the attendant disadvantages. It must also be taken into account that the carbonated ores contain nearly double as much carbonic acid as the hydrated ores contain water. The protoxide of iron contained in the carbonated ores becomes converted into the higher state of oxidation during the roasting process, causing the ores to become porous. According to Wedding, the carbonate of iron, heated without special excess of air, forms $4FeO, Fe_2O_3$. Gruner, however, states that carbonate of iron heated to 300°–400° C. in an atmosphere of carbonic acid gas is converted into a state of oxidation more nearly approaching that of magnetite. If there be plentiful access of air the final product may be Fe_2O_3. The higher the stage of oxidation, the more easily it is reduced, it is therefore clear that the roasting of carbonated iron ore should take place in an oxidizing heat.

It is chiefly in the case of ores containing a considerable proportion of carbon that the roasting must take place in a reducing atmosphere, in order that the whole of the carbon may not be consumed, but that some of it may be subsequently utilized in the blast furnace. In such cases no further fuel need be added to that contained in the ore. Such methods are, however, exceptional, and are chiefly used for black band ores.

Roasting has frequently for its object the conversion of the magnetic oxide of iron into the peroxide, from which latter combination the iron is more easily reduced to the metallic state. But, although such a conversion may be complete, yet a very long time is necessary to effect it in cases where the structure of the mineral is very dense. The best temperature in such cases is a yellow heat, for, according to Tholander, peroxide of iron commences to give off oxygen at a higher temperature under the conditions prevalent in roasting kilns of the ordinary construction.

A very high temperature is only of use when the ore contains a considerable percentage of lime. Tholander's experiments show that calcareous magnetic iron ore, when heated to a temperature slightly above the melting point of silver, forms a compound of lime and peroxide of iron, which begins to melt, but without decomposition. This compound is more easily reduced than the ore in its natural state, but not so easily as free oxide of iron.

It is therefore evident that, in roasting ores containing peroxide of iron, too high a temperature must be avoided. Tholander's researches indicate that even when oxidizing gases have free access to oxide of iron at a high temperature reduction takes place, the proportion of oxygen sometimes sinking below that contained in magnetite. An oxidizing roasting of magnetic iron ore is especially serviceable when the degree of oxidation of the ore is lower than that of pure magnetite. It is invariably found that the percentage of oxygen increases during the roasting of magnetic ores, while the reverse is sometimes the case with hæmatite.

Calcareous or manganiferous ores may also be advantageously subjected to an oxidizing roasting. The protoxide of iron must absorb oxygen before it can combine with the lime, and any protoxide of manganese which may be present also becomes converted in a more highly oxidized compound.

With regard to the oxides of manganese, the same observation may be made as for the oxides of iron: at a low heat oxygen is absorbed, while at a higher temperature it is again given off.

Silicates of protoxide of iron can be decomposed by means of oxidizing roasting. The result is a mechanical mixture of free silica with a combination of protoxide and peroxide of iron. This reaction is of great importance, as the silicate of the protoxide of iron is extremely difficult to reduce direct, because the affinity of the silica to the protoxide of iron must be overcome in addition to the affinity of the oxygen to the metal. Such silicates are, in addition, easily fusible, and are liable to interfere with the action of the blast furnace by melting prematurely. Tholander found that when slag from a puddling furnace was heated to a red heat with access of air it absorbed oxygen and became more and more magnetic up to a certain point. If the roasting were then continued, there was a diminution in the magnetic properties, and white scales of silica were formed. This takes place at a dull red heat; but the change is more rapid at a higher temperature, provided there is no fusion. It is very difficult to oxidize the whole of the protoxide of iron contained in such a slag; in an experiment which lasted 23 hours under highly favourable conditions the oxidation was not complete.

Ores which contain a large proportion of silicate of protoxide of iron are usually of a greyish or dark green colour before roasting. After that operation they assume a yellowish or reddish brown tint. Some silicates of the protoxide of manganese, in which the base predominates, can be easily decomposed by roasting; others which contain more silica are but slightly changed.

Sulphur occurs in ores chiefly in three forms, namely, the different kinds of pyrites, zinc blende, and galena. A very small proportion is sometimes present in the form of sulphates, which may generally be removed by lixiviation. If the heat to which the ores are subjected be not oxidizing, one equivalent of sulphur will always remain for each equivalent of metal, the excess only being driven off. Iron pyrites, the most usual sulphide in iron ores, has the composition FeS_2. At a comparatively low temperature a portion of the sulphur is given off in a gaseous state, and by raising the temperature half of the sulphur may be removed by distillation. But the compound of one equivalent of iron and one of sulphur which remains can, in the absence of an oxidizing substance, be subjected to any heat without losing sulphur. If, however, air be freely admitted, part of the sulphur is oxidized to sulphurous acid, and the final products obtained are sulphurous and sulphuric acids and oxide of iron, or magnetic oxide of iron if the temperature was very high.

In roasting magnetic pyrites the products obtained are the same, with the exception that no sulphur is volatilized in the first instance. When arsenical pyrites $FeS_2 + FeAs_2$ is heated, sulphide of arsenic is distilled over at a dull red heat; then sulphurous and arsenious acids are evolved. The latter acid cannot, however, be completely expelled by heat, so that ores containing arsenic will always be found to retain a certain proportion of that impurity, even after the most careful roasting. Zinc blende is very difficult to oxidize thoroughly. In the first stage of the roasting process, oxide of zinc and sulphate of zinc are formed, the latter salt requiring a white heat to decompose it when in a pure state. Distributed in small particles through iron ores it may, however, be dissociated more easily. Galena is converted into oxide of lead and sulphate of lead by an oxidizing heat; in this case also the sulphate requires a high temperature to decompose it.

In general, sulphides are first converted during the roasting process into a mixture of oxides and sulphates, the latter can then generally be decomposed by the application of a more elevated temperature. Tholander has made some important experiments on the heat required to produce dissociation between the sulphuric acid and the base with which it forms the salt. Two platinum vessels were filled with the sulphate of protoxide of iron and subjected to temperatures of 650° C. and 750° C. respectively. In $1\frac{1}{2}$ hours the contents of the first vessel contained 0·07 per cent. sulphur, which was reduced to 0·004 per cent. on being heated at the same temperature for two hours longer. At 750° C., corresponding with a full red heat, no traces of sulphur could be found after the lapse of $1\frac{1}{2}$ hours. The sulphates of copper, zinc, and lime were heated in a muffle furnace for about 6 hours, when it was found that the residue of the first contained scarcely a trace of sulphur, while the zinc retained 0·1 per cent. of that substance. The sulphate of lime appeared almost unchanged. Sulphate of lime was then heated to a temperature slightly exceeding the melting point of silver (1000° C.), and even then was not decomposed. The sulphuric acid could only be driven off by heating this sulphate to a bright yellow heat over a gas blow-pipe. Sulphate of lead was partially dissociated at 750° C.; but even at this temperature little sulphuric acid was given off.

It appears from these experiments that sulphate of lime cannot be decomposed in the roasting furnace, as the temperature necessary to drive off the sulphuric acid is so high that most iron ores would melt if exposed to it. For the same reason it is difficult to drive the whole of the sulphur out of calcareous ores which contain pyrites. The sulphuric acid produced in the lower part of the furnace from the pyrites combines with the lime in the upper part. These ores are, however, much more easily dealt with than those which already contain gypsum in their natural state, as the sulphate is formed on the exterior of the pieces only.

When iron ores which contain sulphur are roasted in lumps they must be subjected to a much higher temperature than when in a more finely divided state. Although the above experiments show that no very high temperature is needed to free iron from sulphur, yet this only holds good when the ores are in a state of fine subdivision. Large pieces prevent the access of air into the interior, especially if the ores be of a compact structure. In the interior of a lump of ore the oxidation of the sulphur frequently takes place at the expense of the oxygen contained in the oxide of iron itself, and to liberate this a high temperature is necessary.

The sulphur can be expelled much more easily from ores consisting chiefly of peroxide of iron than from magnetite, because the latter requires a higher temperature to liberate oxygen. As a general rule, it may be said that the looser the structure of the ore, the more easily is the sulphur, present in the form of pyrites, oxidized.

In the interior of pieces of very dense ore particles of pyrites are frequently found which are but imperfectly freed from sulphur. The presence of sulphur may be detected in such cases by

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moistening the ore with sulphuric acid, when, if sulphur be present, sulphuretted hydrogen will be evolved. The application of great heat has the advantage of fusing the sulphides in the interior of each lump; they can then reach the surface of the ore, and are more easily oxidized.

The presence of carbon can be of advantage in expelling the sulphur from pyrites. The sulphuric acid formed by the oxidation of the pyrites is converted into sulphurous acid by carbon at a comparatively low temperature. Care must be taken not to raise the temperature too much, or sulphide of iron might again be formed. In roasting calcareous ores it is of importance that the sulphur should be expelled in the form of sulphurous and not sulphuric acid.

Although heated sulphide of iron decomposes steam, yet it appears doubtful whether any advantage is derived from the presence of the latter during roasting. The end products obtained by its action upon pyrites in the presence of air are oxide or magnetic oxide of iron and sulphurous acid. The same products are obtained when aqueous vapour is entirely absent.

In some exceptional cases it is found advantageous to lixiviate the ore or to expose it to the weather after a comparatively light roasting. At Kladno, near Prague, one of the largest iron-works in Bohemia, ores containing 1·7 per cent. sulphur are first roasted at a low temperature, which brings the sulphur down to 0·5 per cent., and are then placed in basins, the water of which is renewed every second day. In six or eight weeks the proportion of sulphur sinks to 0·1 per cent.

As roasting is only a preparatory operation previous to reduction in the blast furnace, it might be supposed that the more oxygen is driven out of the ore at first, the easier will be its subsequent reduction. Generally, however, the very opposite is found to be the case; the more oxygen is absorbed during roasting, the more readily will the ore be reduced. The explanation of this fact must be looked for in the different zones of heat which are found in a blast furnace. It is highly probable that when ores consisting of peroxide of iron descend in the blast furnace they are soon reduced to magnetic oxide, which is more porous and accessible to the action of the reducing gases than if the ore had originally been fed into the furnace in the lower stage of oxidation. When ores in their natural state are oxidized to their highest degree, little is to be gained by roasting them in a reducing atmosphere.

Hæmatite when free from sulphur is but slightly improved by roasting unless its texture be so dense that the mechanical action of heat is necessary to render it porous. With magnetite the case is very different. The proportion of oxygen contained in it can be increased either by oxidizing roasting at a low temperature, or by heating it until it clinkers, allowing access to the air. The silicates of the protoxide of iron, which are usually associated with magnetite, are oxidized during roasting, and can subsequently be reduced without difficulty. In general it will be found more advantageous to roast such ores at a moderate temperature than to heat them until clinkering begins.

When iron ore is reduced at a low temperature, 350°–450° C., by carbonic oxide, carbon is usually deposited while carbonic acid is given off, according to the reaction: $2CO = C + CO_2$. This takes place in the upper part of the blast furnace, and has an important bearing upon the consumption of fuel. The more carbon is separated in this manner from the escaping gases, the less fuel will be required to effect the reduction of the ore. On this point also Tholander has made a series of experiments. He found that the more oxygen is absorbed by a magnetic ore during roasting, the more carbon is separated by that ore when heated with carbonic oxide. Hæmatite which had been slightly reduced during roasting, showed less power of absorbing carbon.

The appearance of the roasted ore is generally sufficient indication whether the operation has been well conducted or not. The roasted ore is less sonorous when struck with a hammer than the fresh, and is also much more brittle. Its diminished density depends partly on the expulsion of water and carbonic acid, as in the case of hydrated and carbonated ores, sometimes, however, it is due to numerous small cracks, frequently invisible to the naked eye. All ores containing greenish silicates of iron should be roasted until the colour changes to reddish brown or reddish yellow. Well roasted ore should have the same appearance on the outside and inside of each piece, when broken open. If the lumps contain kernels similar in appearance to the fresh ore it is an indication that the operation has been too hastily performed. It cannot, however, always be expected that the degree of oxidation should be as complete in the interior of lumps of magnetite as on the exterior. Ores which do not require a high roasting temperature to drive out sulphur should have a red colour externally, gradually becoming less defined towards the centre of each piece. It is only in cases where the ore is extremely dense in its natural state that it becomes impossible to produce this red colour during roasting.

Those ores which require a clinkering heat during roasting should possess the bluish grey colour, characteristic not only of the magnetic oxide of iron, but also of the fused peroxide. In the case of very poor ores the colour may be modified by the gangue; but even here the eye can easily distinguish whether the purer particles of ore have been sufficiently roasted or not. Should it be observed that the ore has entered into combination with the siliceous gangue, it is an indication that there has been a reducing atmosphere in the roasting kiln, and that the temperature has been raised too rapidly to the clinkering point. Where the ore has been clinkered it is a good sign if the fractured surface of the pieces has a shining appearance, as the clinkered peroxide of iron possesses more brilliancy than the magnetic oxide. A rough exterior of each piece is to be preferred to a smooth enamel, the latter being produced when the ore is heated too rapidly.

The most ancient mode of roasting iron ore was to mix it with the fuel, the combustion of which produced the heat required. This method is necessarily very imperfect, and cannot be compared with roasting in kilns furnished with separate heating apparatus or gas generators. Roasting in contact with fuel is specially injurious when the ore has to be subjected to a very high temperature. This can only be attained by adding more fuel, so that the danger of reducing the ore is increased. It frequently happens that iron is reduced to the metallic state under such

39993

circumstances. Another defect of this system is the difficulty of obtaining uniformity; much more care and skill are requisite to avoid loss in this respect. In the first instance the proportion of fuel must be rightly determined and distributed; then an excessive draught must be damped by means of fine ore and coal slack, and when the draught becomes too slow it must be accelerated. Where ore has to be carefully roasted it must not be mixed with the fuel; but in cases where it is only intended to drive off carbonic acid and water such a method may be suitable.

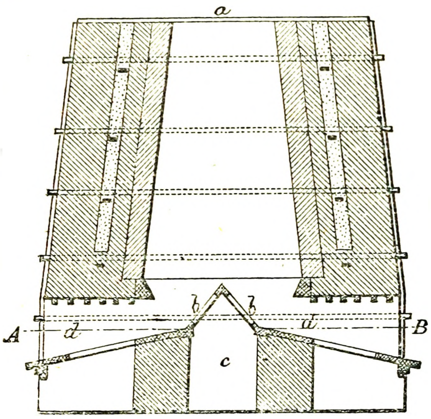
In places where fuel is abundant, ore is still treated by this imperfect method of roasting in heaps. A level piece of ground is chosen and a foundation made upon it with faggots of wood. Upon this the ore and coal are placed, the heap thus formed being covered over with coal slack. The wood is then fired and fresh ore and coal are added as the fire progresses.

Roasting in pits or enclosures is somewhat similar to the method just described. The chief difference is that the heap of ore and fuel is surrounded by walls, which facilitate the regulation of the draught and economize fuel. At the same time the ore is roasted more uniformly than in exposed heaps. Where the ground is favourable, it is advantageous to build at least one of the walls against the side of a hill; but where the ground is level the sides of the enclosure must be built strong enough to sustain the weight of the ore and fuel. The dimensions of such pits vary from 16–24 ft. square, the height of the walls being 5–7 ft. One side is usually left open or provided with a large aperture for charging and emptying the pit.

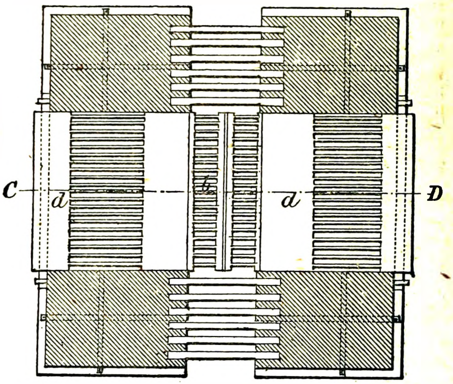
The floor is first levelled and then covered with pieces of wood and faggots. Upon these a layer of fine coal is spread, then ore and coal alternately. The whole heap is covered with coal slack to prevent the fire from rising too rapidly. In order to increase the draught in the corners, where it would otherwise be insufficient, pieces of wood are placed upright against the walls and are removed as soon as the pit is filled. This method of roasting is necessarily intermittent; a pit is filled, the fire allowed to burn out, and the ore removed when cool. Each pit requires about one week to burn. The amount of fuel used is very variable, and even under the most favourable conditions part of the ore is imperfectly calcined and must be added to the next charge. The roasted ore is, where possible, allowed to remain exposed to the atmosphere for several months, in order that the sulphates may be washed out by the rain. This method of roasting in pits is now only employed under exceptional circumstances, for instance when a new blast furnace has to be started.

In most cases where the ore is roasted in contact with the fuel, usually coal slack, pit kilns are now used. One of the most simple forms is Schedin's, the construction of which will be apparent from Figs. 1526 and 1527. The ore and fuel are fed in alternately at *a*, Fig. 1526, and the roasted ore is drawn at *d* when sufficiently cool. The air necessary for the combustion of the fuel enters partly through *d*, and partly through the flue *c* and the inclined grating above it, *b*. The greatest heat is at the top of this kiln, consequently the more quickly the ore is drawn the more regular will be the distribution of heat throughout the mass. But if the ore requires to be calcined to the clinkering point, it cannot be drawn until the whole of the fuel in the lower part of the charge is consumed. Should the mass become so clinkered that its own weight is insufficient to bring it down, it must be broken away by means of a heavy bar of iron worked from above. There is less chance of an interruption through clinkering in the working of this kiln if the fuel is allowed more time for complete combustion.

1526.



1527.



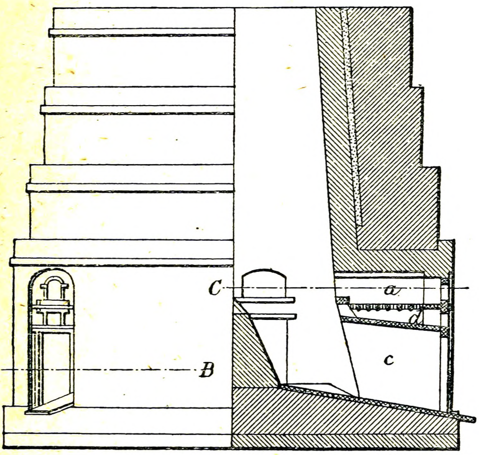
The height of the kiln should be so regulated that the ore has sufficient time to cool before arriving at the bottom. If too high, the cost of raising the materials to the top becomes very great. When the kiln is too low and the ore has to be drawn warm there is a considerable loss of heat. The size must therefore be calculated according to the quantity of ore to be roasted and the temperature to which it must be raised. Finely divided ore must remain longer in the kiln than lump ore, as the fuel takes longer to burn completely. It is much more advantageous with this form of kiln to have the ore in pieces of a small size, for if the lumps are large there is a greater passage for the air and products of combustion in that part adjoining the walls than in the centre, and a consequent irregularity in the roasting. The production of Schedin's kiln, where the ore does not require to be heated to a very high temperature, is about 12 truck-loads in 4½ hours. About 4 truckloads are emptied into the kiln at once, then a corresponding quantity of coal slack. The finer particles of ore should, as much as possible, be distributed round the sides of the kiln, in order to counteract the tendency of the draught to break through at that spot. It is of importance to arrange the ore at the commencement in such a manner as to secure regularity of draught, as it is very difficult to change the direction of the fire once it begins to break through.

This form of kiln affords special facilities for roasting finely divided ore; about two-thirds of ore in small pieces or powder can be mixed with one-third of lump ore. In Sweden, when very fine ores are to be roasted, part of the fine coal is replaced by short pieces of wood, which keep the mass more open. It has been found that in roasting calcareous iron ores, less sulphate of lime is formed in the Schedin kiln than in others heated by separate fires or gas generators. This is partly due to the fact, that less sulphuric acid is formed when sulphides are roasted in contact with carbon, than when gases only are the heating agents. Another advantage is, that the zone of greatest heat being situated at the top of the charge, the sulphuric acid evolved passes through a thinner layer of calcareous matter than where the heat is applied below.

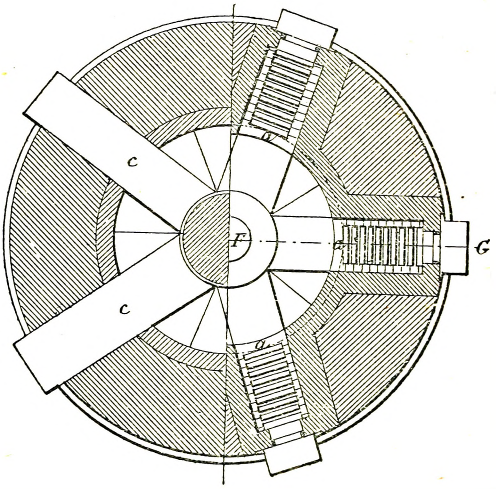
Some of the Swedish ores are so pure that the only injurious substance contained in them is a small proportion of sulphur. It was found that this impurity could not be completely removed in the old form of kiln, and numerous experiments were tried with different kinds of kilns. Sefström appears to have been one of the first to construct a calcining kiln in which the fuel did not come into actual contact with the ore. His form of kiln did not, however, succeed in practice, chiefly because, the greatest heat being in the centre, the ore clinkered at that spot and could not be reached and broken away by an iron rod.

Sefström's kiln came into use contemporaneously with von Uhr's, which is shown in Figs. 1528 and 1529. The five furnaces *a* are built into the walls of the kiln. The bottom of the ashpit *d* forms the roof of the draw-hole *c*. This arrangement does not utilize the heat to the fullest extent, as the ore has to be drawn hot; but it has the great advantage that the interior of the kiln is easily accessible, so that a full clinkering heat may be applied. The working of this form of kiln much resembles that of Westman's gas-kiln described below.

1528.



1529.



The first calcining kilns in Sweden to utilize the gases from the blast furnace were those of Starbäck. The details of construction are given in Figs. 1530, 1531. The gases enter at the holes *b*, while the calcined ore is drawn out at *a*.

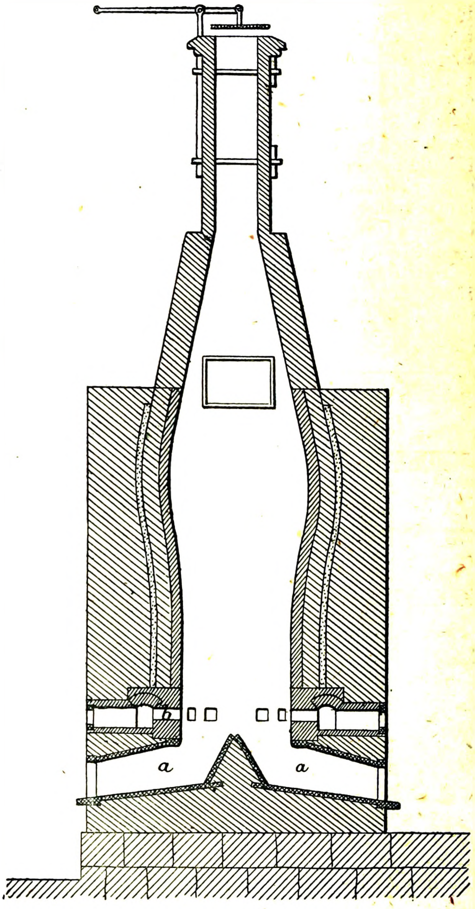
Numerous endeavours were made to improve upon this form of kiln and to develop the idea of the utilization of the blast furnace gases. The most successful construction was that of Clason, still in frequent use, especially in Sweden, where it is better known by the name of the Tenninge kiln, from the place where it was first erected.

Figs. 1532 and 1533 show the arrangement of this kiln in its present shape. The waste gases from the blast furnace enter through the pipe *a*, which discharges them into the circular flue *b*, *c* is a recess for the reception of ashes, and *d* an opening for cleaning the flue itself. From *b* the gases rise through the vertical flues *e* into the openings *f*, which admit them into the kiln. The amount of gas entering is regulated by means of the bricks *g*, which slide backwards and forwards. Above the openings *f* are other apertures *h*, through which clinkered masses of ore can be broken loose by means of an iron bar. At a considerable depth below the gas inlets are the four draw-holes *i*. The top, *k*, is open; but all other orifices are closed by cast-iron doors.

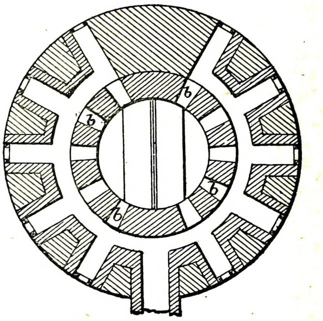
The Tenninge kiln possesses the great advantages over Schedin's, that the calcination can be made more oxidizing and that there is considerable economy in fuel, waste heat alone being used. It has, however, several defects, one of the most serious of which is that when the heat is raised to the clinkering point the ore is liable to cake and cannot be brought to run down regularly. The kiln must then be stopped and the masses adhering to the walls broken away. To avoid this it is necessary that the contents of the kiln should be easily accessible in the neighbourhood of the gas inlets; but this is difficult to attain without completely altering the construction.

It has been found in practice that the ore is not quite uniformly roasted in this kiln. The chief reason for this seems to be that the source of heat is adjoining the exterior walls, so that there must be a diminution of temperature towards the centre of the mass of ore. The flame and the heated products of combustion may, if the draught be good, ascend in the direction of the dotted lines, Fig. 1532; but even in this, the most favourable case, it is evident that their temperature must have considerably diminished before they reach the centre. The greatest heat must, therefore, always prevail in a belt adjoining the wall of the kiln. The ore which passes down through this roasting belt is well calcined, and the best method to secure uniformity would be to draw those portions of the ore only which have passed through this belt or zone. The construction of the Tenninge kiln, however, renders this impossible, as the ore from the centre slides down towards the outlets mixed with that from the periphery. Various modifications have been proposed to remedy this defect, of all of which that of A. Jansson appears to have met with most success. A cast-iron pipe 5–6 ft. long, and 5–6 in. internal diameter, hangs down into the centre of the kiln. The pipe being empty and surrounded by ore, the draught is strongest immediately underneath it, and the gases are drawn towards the centre sooner than would otherwise be the case. By this means the width of the roasting girdle is increased. The central draught can be regulated by means of a brick placed upon the upper end of the tube.

1530.



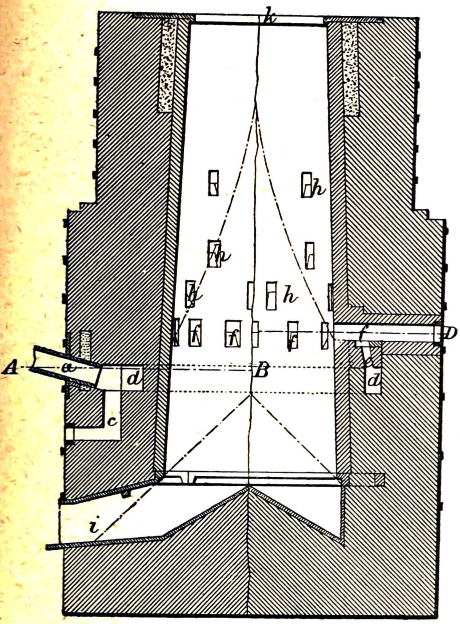
This form of calcining kiln is undoubtedly advantageous for ores containing little sulphur, and which do not therefore require a high temperature during roasting. With such ores the presence of a few lumps of badly roasted material is seldom injurious. The Tenninge kiln has this advantage over Westman's kiln, that the amount of gas wasted is not so great, the heat being more economically applied in the lower part of the kiln. In spite of this the Tenninge construction is gradually being superseded in Sweden by that of Westman. The chief reason for this appears to be that the ores are required to be free from sulphur before they enter the blast furnace, and there are few places where the mineral is found sufficiently pure to be advantageously calcined in the Tenninge kiln. Westman's kiln, on the other hand, is capable of removing the sulphur from ores containing a considerable quantity of pyrites. It has been already mentioned that a clinkering heat is necessary in calcining ores containing lime and pyrites at the same time. The mineral of the Dannemora district is of this nature, and it was here that the first Westman kiln was built. A Tenninge kiln was constructed at Söderfors under the superintendence of C. Westman. As soon as it was started, Westman found that the ore could not be roasted in it so thoroughly as in the Uhr kiln, which had previously been in use. He came to the conclusion that this was not due to the fuel; but to the difficulty in obtaining access to the ore in consequence of the construction of the kiln. Westman then proposed and built another form of kiln, which, although differing in some details, was yet the same, as regards the fundamental principle, as that now in use.



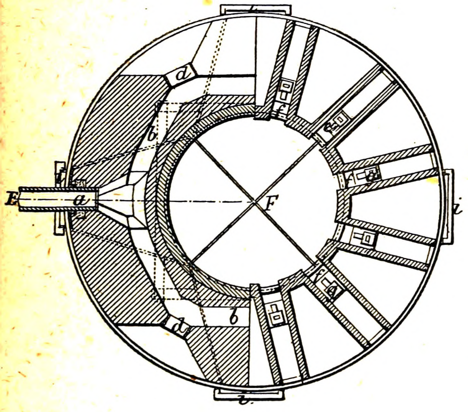
1531.

The present form of Westman's calcining kiln is given in Figs. 1534 to 1538, Fig. 1534 being a sectional elevation taken through the line C A B of Fig. 1535. Fig. 1537 is a plan through D E, the right half of Fig. 1536 a plan on F G, the left half partly on H I and partly on K L, the upper portion of Fig. 1535 to the left plan on N M, the lower portion plan on O P, and the right plan on Q R of Fig. 1534, respectively. Fig. 1538 relates to a detail of the lower portion. To prevent the ore from hanging against the sides when clinkered together the lower part is made wider than the upper. The blast furnace gases enter the annular cast-iron pipe *c* through the vertical pipes *a*. They are then distributed by means of the horizontal pipes *d* through the openings *f* into the kiln. The supply is regulated partly by valves in the main, partly by cast-iron plates which can be moved backwards and forwards over the apertures *e*. The draw-holes *b* are so situated underneath *f* that the ore can be reached in any part by means of iron bars. The vertical distance between the draw-holes and the apertures for the admission of gas is very slight, the latter being situated immediately above the iron girders *g*. As near above *f* as is consistent with the strength of the kiln are the holes *h*, through which bars can be inserted to loosen the charge. Above these again is another row of holes *i* for the same purpose. These holes are all placed so close together that

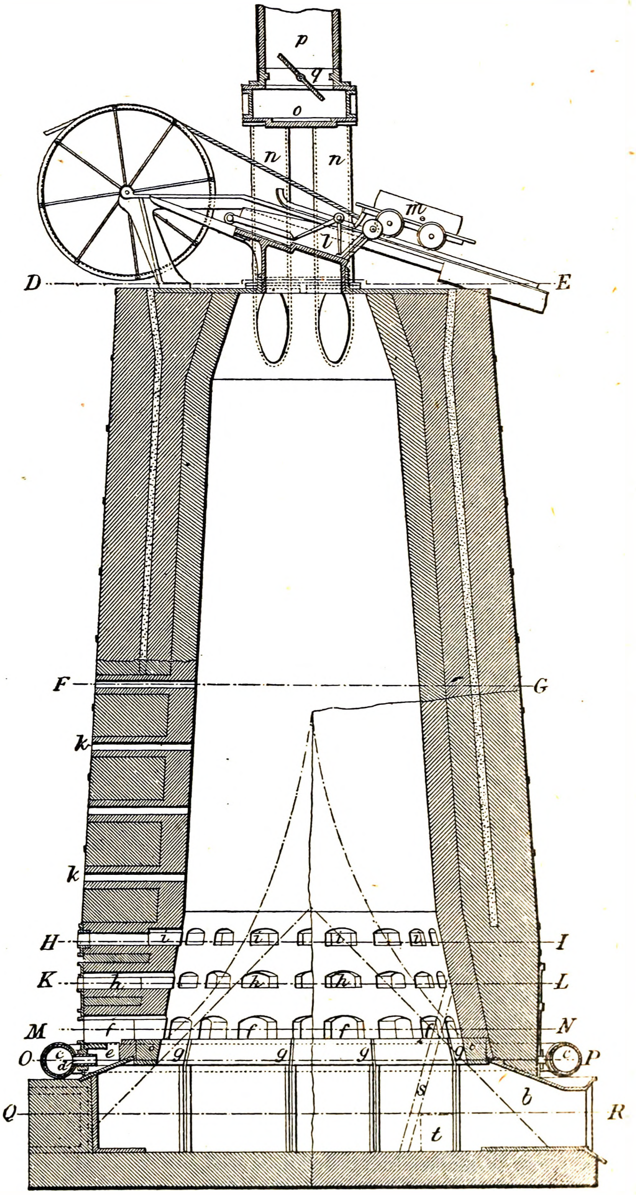
1532.



1533.



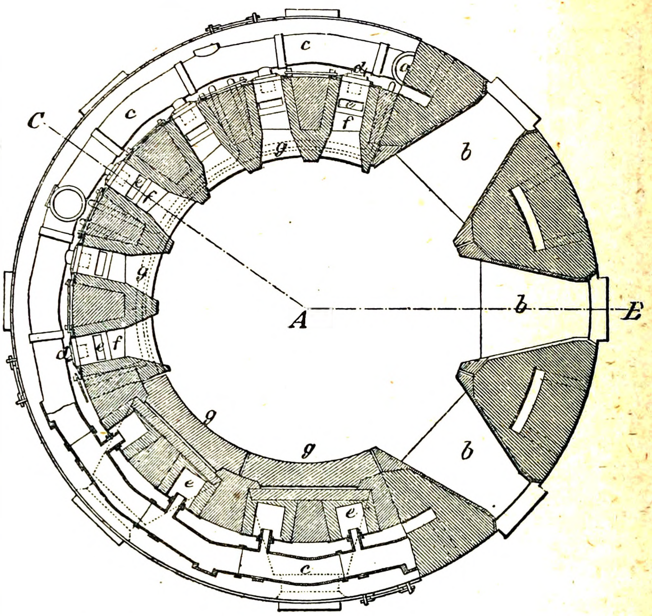
1534.



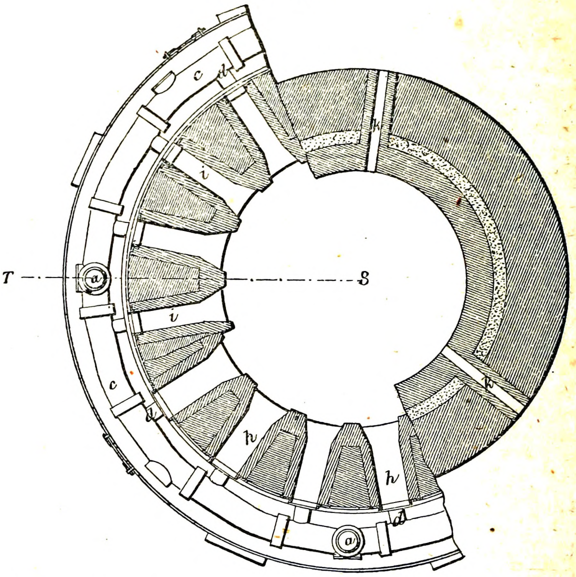
the contents of the kiln are as accessible at their level as below *f*. Above *i* are several rows of holes *k* for observing the progress of the roasting. All apertures are provided with cast-iron doors. The doors of the draw-holes are furnished with five small holes for the admission of air; these can be closed by means of slides when necessary. The top of the kiln is closed by a lid *l*, which is opened automatically by the small truck *m* as soon as ore is raised to the top. *m* runs between two cast-iron pipes *n*, which communicate with the kiln, and are surmounted by the cast-iron case *o*. Upon *o* is fixed a chimney *p*, the draught through which can be regulated by the damper *q*. Sometimes Westman's kiln is built without chimney, the top being left open like the Tenninge kiln.

The shortness of the space between the draw-holes and the gas apertures is of the greatest importance in working ores which require a clinkering heat. When the charge is not accessible in the immediate neighbourhood of the source of heat, it is very liable to cake in such a manner as to stop the working of the kiln. Although in Westman's kiln the greatest heat is at the sides, similar to the Tenninge construction, yet the cone of badly-roasted ore in the centre is much smaller, as may be seen from the dotted lines Fig. 1533. The heat has more access to the ore, so that the calcining takes place more uniformly. In breaking down the ore from the holes above the gas inlets the centre cone can be allowed to remain, so that the proportion of imperfectly roasted ore is reduced to a minimum. One disadvantage of the proximity of the gas inlets to the draw-holes is the necessity of drawing the ore while still hot. A considerable amount of heat is thus lost, which is utilized in the Tenninge kiln to heat the air necessary for combustion. The great number of observation holes facilitates the breaking up of clinkered masses of ore to such an extent that there is no danger of stoppage from this source. It is, however, advisable to reduce the number of these holes as much as is consistent with efficiency, because there is a considerable loss of heat from radiation through the cast-iron doors. With some ores, which are not required to clinker during calcination, the upper series of apertures may be omitted or their number reduced. The girders upon which the ore rests are sometimes made hollow, so that they may be cooled by air circulating through them. The number of draw-holes may vary from five to eight; for each draw-hole there are two gas inlets. The average production of a Westman kiln is about 4¼ tons in 24 hours for each draw-hole. Although the size of the kiln may be increased where a large quantity of ore is to be roasted, yet there is no advantage in going beyond eight draw-holes, because the material in the centre would be imperfectly calcined were the diameter of the kiln too great. In working Westman's kiln, several precautions must be taken. In the first place, all hollow spaces in the charge must be avoided as much as possible. The roasted ore should be withdrawn regularly, so that the superincumbent portions can settle down gradually. If this were not attended to, some parts of the ore would be more calcined than others. The ore which lies at the bottom of the draw-hole is first removed with the help of an iron rake. A further quantity is then broken down by another workman stationed at the openings above the draw-hole. Where the ore is much clinkered during calcination three men may be necessary; but two are usually sufficient. In breaking down the ore, care should be taken that it does not fall in very large lumps, these being difficult to remove from the girders. As soon as sufficient ore has been withdrawn the upper part of the charge is brought down by means of bars applied through the upper openings.

1535.

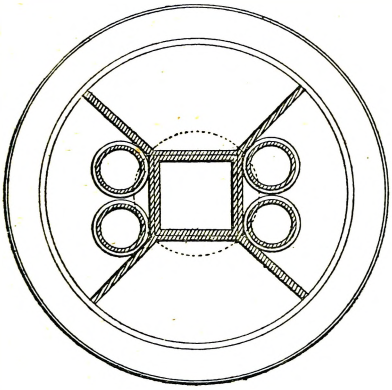


1536.

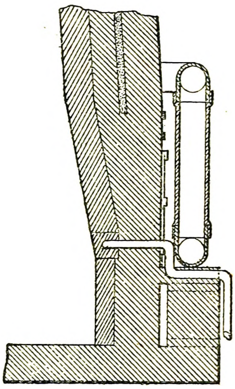


The waste gas produced by the blast furnace is very variable in composition. The ratio of the carbonic acid to the carbonic oxide may oscillate between 1·3 and 0·35 by weight. The greater the proportion of carbonic acid, the more perfect has been the utilization of the fuel in the blast furnace; but the worse for heating purposes is the gas produced. In the combustion of the gas an excess of either carbonic acid or air is injurious, as they would absorb heat, without aiding in the production of it. As, however, the heat must be oxidizing, a certain excess of air is requisite in Westman's kiln. The gas enters with a slight pressure, which may equal a column of about $\frac{1}{2}$ in. of water. The appearance of the flame as it enters the kiln is a good indication whether the supply of air is sufficient or not. The farther the flame penetrates into the kiln, the more air is passing through; but if it tries to escape outwards, it is a sign of a block in the kiln. It might, at first sight, appear that the heat would be greatest where the gas comes into contact with the ore; but it is found in practice that this is not the case; but that the highest temperature prevails at a more elevated point, where the gas becomes mixed with sufficient air to ensure perfect combustion. The less draught there is in the kiln, the lower will be the zone of heat, and the darker will be the appearance of the ore when examined through the apertures adjoining the gas inlets. If, however, roasted ore has just been withdrawn from the kiln the heat of the ore opposite the gas inlets will appear greater then if examined some time afterwards. It is of great importance to maintain the dimensions of the roasting zone, or annular space of maximum heat, constant. Variations may take place either in a vertical or horizontal direction. The chief causes which tend to increase the height of the roasting zone are: Increasing the draught in the kiln by opening the damper; coarser ore; a shorter column of ore; a higher temperature in the upper part of the kiln; colder weather; and, finally, the addition of coal slack, provided it burns in the upper part of the kiln. Diminishing the amount of ore drawn also tends to raise the roasting zone. The zone of greatest heat will sink when the contrary of the above conditions prevails, also when the ores clinker easily, or when they contain a large proportion of pyrites. In the latter case, the sulphur of the pyrites acts as fuel, increasing the temperature in the interior of the charge. The horizontal thickness of the roasting zone can be altered by the method of breaking away the ore with bars. If the bars are worked as far as the centre cone the zone will attain its greatest thickness; if only a small portion of the clinkered ore be broken away, then the zone will become narrower. Each kind of ore requires a different thickness of roasting zone. Once this thickness has become altered, it is liable to still further change, so that the amount of ore badly roasted may be very considerable. When the draught in the kiln is too great the temperature of the ore opposite the gas inlets will be low, and an inexperienced workman, finding the ore cool at the draw-holes, is apt to think that it is insufficiently roasted, and to cease drawing. This will, however, only increase the temperature in the upper part of the kiln, and aggravate the error instead of remedying it. In such a case the ore may clinker in the upper part of the kiln to so great an extent that it cannot be brought down. The gas must then be turned off and, as soon as the clinkered ore begins to cool, it will fall to pieces.

1537.



1538.



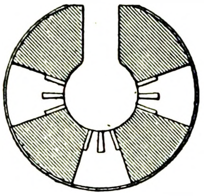
A good chimney provided with a valve or damper is essential in working the kiln. Where a chimney is absent, the size of the lumps of ore is the only means of regulating the draught, and even with a chimney it is necessary to take this into account. Various minor causes may affect the draught, and these can only be counteracted effectually with the help of a chimney. For instance, the draught is usually greater during the night than in the daytime, owing to the reduced temperature of the atmosphere. In some cases, the blast furnace may not supply a sufficient quantity of gas. When this happens, the roasting zone becomes so narrow that the ore will not clinker. An addition of coal slack then becomes necessary in the proportion of 1 part of coal to 8 or 12 parts of ore. Ores which are very easily fused, and contain at the same time a considerable quantity of pyrites, may require a second roasting before they are sufficiently free from sulphur. When much lime is present in the ore, the depth of the roasting zone must be diminished as much as possible. In order to produce a certain quantity of ore in a given time two methods are available. Either large quantities of ore can be drawn at long intervals or small quantities at short intervals. The time between each drawing may therefore vary between 1 and $2\frac{2}{3}$ hours. Much depends upon the character of the ore to be calcined. In general, the greater the heat to which the charge is subjected, the more frequently must portions of it be withdrawn, while ores which do not require a clinkering heat may be taken out in larger quantities. It must be remembered that each time ore is removed the roasting zone sinks a proportionate distance. It then rises again gradually until the operation is repeated.

Should any change become necessary in the character of the ore to be roasted, it must take place gradually by adding little by little portions of the new ore. If the temperature required for the calcination of the new ore be different, the supply of gas and the draught must be regulated as the character of the charge changes. The roasting of mixed ores requires great care; those of a calcareous nature must not be mixed with others whose gangue is siliceous, especially if the latter be rich in pyrites. The mixing takes place in the kiln itself, by tipping in a certain number of truck-loads of each kind of ore. The whole of the ore should not be tipped into the same spot in the kiln, because the finer particles would remain at the place where they fell, while the larger pieces would roll towards the sides of the kiln. Very fine ore has such an influence upon the calcination that the greatest care must be bestowed upon its uniform distribution. When the ore is very dusty, the finer portions have a tendency to fall through between the lumps in such a way that they may arrive at the draw-holes before they are sufficiently calcined. If, therefore, very fine ore be tipped on one side of the kiln, the roasting zone will become depressed on that side, nor can any increase of draught prevent this from occurring. The only remedy is to draw more ore on the opposite side.

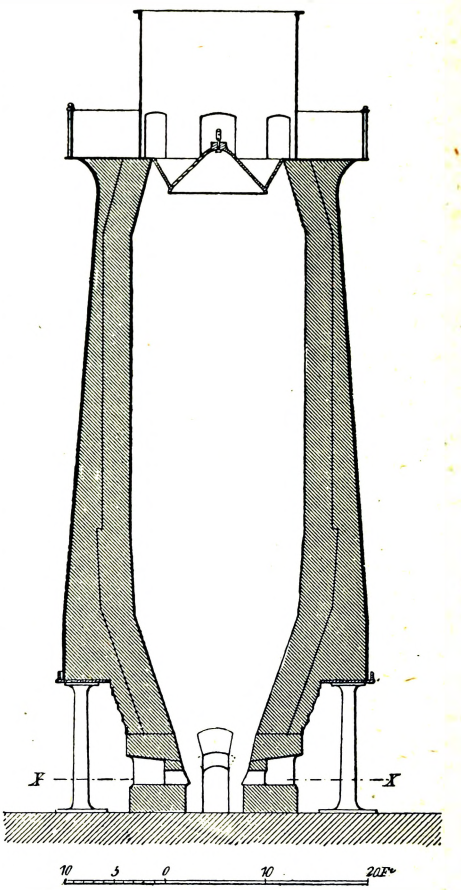
In setting fire to a Westman's kiln for the first time, some preliminary steps are necessary. The gas inlets and other openings are filled with firewood, to prevent injury to the corners from the falling ore. The bottom of the kiln is covered with a layer of ore 2 ft. to 3 ft. deep. Upon this the ore is then tipped, with a small proportion of coal slack. Sometimes it becomes necessary to set fire to a kiln which is already charged with ore. In such a case the best plan is to insert firewood through the gas inlets and other apertures. The combustion of this wood will then produce sufficient draught in the kiln to permit the operation to be conducted in the ordinary manner. The ore which is drawn out at first is necessarily imperfectly roasted. It should be allowed to cool before returning to the kiln, for if it were introduced warm into the upper space the draught would be increased and the roasting zone would consequently rise. Where there is any choice of ore, that which clinkers most easily should be selected for starting the kiln.

Even with the most perfect calcining kiln, portions of the ore will sometimes pass through imperfectly roasted. With many kinds of ores this is not of great importance; but where the raw material contains a considerable proportion of sulphur, the badly roasted pieces must be picked out by hand and returned to the kiln. Should the whole contents of the kiln be insufficiently roasted, it may sometimes become necessary to pick out the clinkered pieces and to calcine the residue again.

1540.



1539.



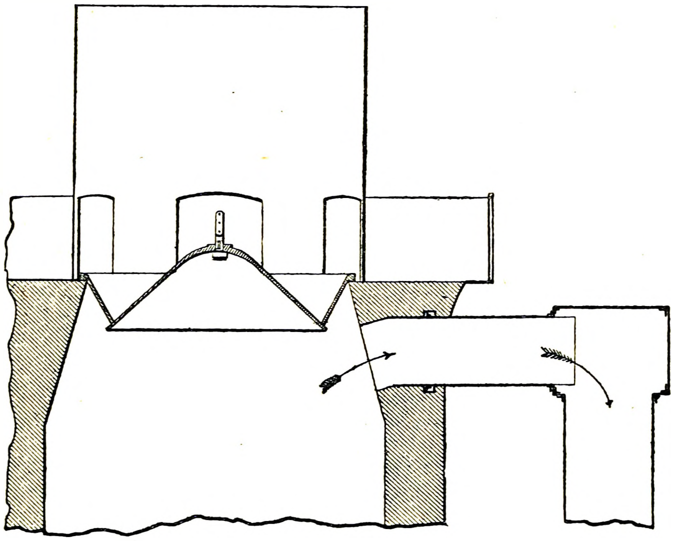
The blast furnaces of the hæmatite district are much the same as those at work in Cleveland, but the appliances for working them are not usually quite so good. Those at work at Barrow may be taken as a fair type of most hæmatite furnaces as to size and capacity; they are about 55 ft. high and 16 ft. diameter at the boshes, having a capacity of about 9000–10,000 cubic ft. The furnaces at the Furness Iron and Steel Works, Askam, are 67 ft. high and 19 ft. diameter at the boshes, tapering to 18 ft. below the gas outlet, Figs. 1540 to 1542; and they have a capacity of 13,100 cubic ft., which is stated to be greater than that of any other hæmatite furnaces at present working. The various attempts which have been made to work larger furnaces for hæmatite ores do not seem to have been attended with such success as to justify the erection of others; and in one or two instances where furnaces of 75 ft. height have been erected, the results obtained have been so unsatisfactory that the furnaces have been blown out and the height diminished to 55 or 60 ft. The Askam furnaces of 67 ft. height did not work well for some time when they were first blown in; the cause of their bad working was attributed to the smallness of the charging bells in proportion to the width of the furnaces, and consequently larger bells were substituted. These furnaces work with great regularity, each producing weekly from 400–460 tons of iron, a large proportion being of a quality suitable for Bessemer converters.

The general form of these furnaces is shown in Figs. 1539 to 1541, and the principal dimensions are as follows;—

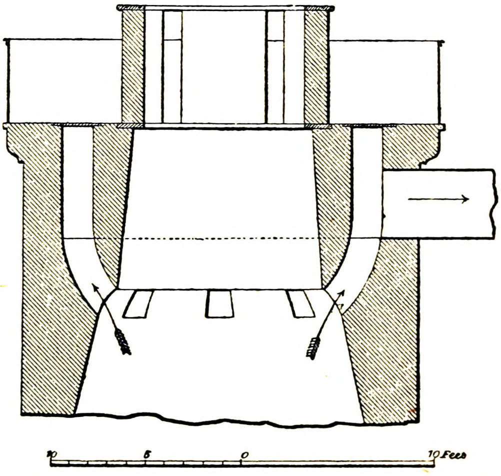
Height	67 ft.
Diameter at boshes	19 ,,
,, throat	18 ,,
,, hearth	7 ,,
Heating surface	5500 square ft.
Number of tuyeres	6
Area of blast inlet	75 square in.
Pressure of blast at engine	3 lb.
,, ,, tuyeres	2¾ lb.
Area of gas outlet	18 square ft.
Diameter of charging bell	12 ft. 6 in.
Weekly make of iron each furnace	400–460 tons.

The arrangement of furnace top shown in Fig. 1542, or some modification of it, is usually adopted where the gas from open-topped hæmatite furnaces is utilized, the gas being taken off through a series of openings round the furnace throat, which is contracted in diameter more abruptly at that part. This construction is found to answer the purpose of distributing the materials very fairly, and at the same time of taking off a large proportion of the gas to the stoves and boilers, but it can only be looked upon as a compromise. A semi-closed top is used at the Barrow furnaces, in which the gas is taken off through a central gas tube as well as through openings round the furnace throat.

1541.



1542.



Of the materials used in the production of hæmatite iron the principal is the hæmatite ore, found in North Lancashire and Cumberland, which occurs in two varieties, one hard, compact, and almost free from moisture, and the other soft and wet. The hard ore is almost invariably used in the production of hæmatite pig iron, and is therefore called blast ore; while the softer quality is used for fettling puddling furnaces, and is called puddling ore. The blast ore of Whitehaven and Furness does not differ much in quality, both districts yielding good and bad varieties; but the best Whitehaven ores are richer in iron than the best Furness ores. In Furness the poorer blast ores usually contain about 45 per cent. of metallic iron, while the better qualities run up to 57, and in some cases 60 per cent.; in Whitehaven the poorer ores contain about 50 per cent. of metallic iron, and the best run up to 60 or 65 per cent.; but the average percentage of iron in the ores used in both districts is probably between 57 and 60 per cent.

In this ore the principal impurity is silica; and unlike the Cleveland and most other ores, it does not contain any alumina. It is therefore thought desirable at many places to mix it with aluminous ores, for the purpose of producing a better slag, and also in order to obtain greater regularity in the working of the furnace. The addition of these aluminous ores also gives the means of controlling in some measure the percentage of silica in the iron.

The aluminous ores are also obtained from Ireland, and are so readily accessible that they can be had at a reasonable cost. Three principal varieties of Irish ores are used in the manufacture of hæmatite iron, and these are fairly represented by the three ores known as lithomarge, red aluminous iron ore, and black nodular iron ore. The accompanying table shows their respective composition;—

ANALYSIS OF ALUMINOUS IRON ORES.

	Lithomarge.	Red Aluminous Ore from Larne.	Black Nodular Ore from Red Bay.
	per cent.	per cent.	per cent.
Silica	30·70	11·25	6·00
Alumina	27·05	35·61	20·37
Titanic acid	trace	trace	0·75
Peroxide of iron	25·05	34·65	71·63
Protoxide of iron	trace	none	0·68
Magnesia and lime	1·11	trace	trace
Water of combination	15·85	16·30	1·15
	99·76	97·81	100·58
Percentage of metallic iron ..	17·53	24·25	50·67

From this it will be seen that the proportion of alumina to silica in the lithomarge is about in equal quantities, being 27 and 30 per cent., while in the aluminous ore from Larne, and the black nodular from Red Bay it is about 3–1; the red variety containing about 35 per cent. of alumina against 20 per cent. in the black nodular.

The lithomarge has been longest in use, and is preferred at some works; but some believe the other two varieties to be better for most purposes, because the percentage of silica in the lithomarge is so high in proportion to the alumina that a very large quantity of the ore must be used to produce any appreciable difference in the composition of the slag, and in the smelting of the materials in the furnace. A still more serious objection to the lithomarge is the high percentage of moisture it contains, which must have a very injurious effect in cooling the escaping gases of the furnace, and thus increasing the consumption of fuel a ton of iron. In addition, moreover, to containing water of combination, lithomarge has a great attraction for moisture, and generally contains from 5–10 per cent. of hygroscopic water, which has also to be vaporized and raised to the temperature of the escaping gases; and if to this be added the coke requisite for melting 4 cwt. of material which can scarcely be called iron, the total loss of fuel amounts to at least ¾ cwt. of coke to the ton of iron made; meaning a reduced make, and therefore an increased cost not fully represented by the increased consumption of coke alone.

The red aluminous ore has also the disadvantage of containing usually about 15 or 16 per cent. of moisture; not only causing a waste of fuel, as in the case of the lithomarge, but the red ore having also a tendency to fall to powder, the contained moisture causes it then to assume a pasty condition, which leads to bad distribution of the materials in the furnace, and the ore is thus mechanically objectionable. The black nodular ore from Red Bay is free from the objection of containing combined water, and owing to the compact character of the nodules it does not so readily absorb moisture as either lithomarge or red aluminous ore; and as it contains a high percentage of iron, amounting to as much as 50 per cent. of metallic iron, with a large excess of alumina over silica, the proportions of the two being 20 and 6 per cent. respectively, it affords the means of neutralizing the effect of the silica in the hæmatite ore, without increasing the consumption of fuel a ton of iron made, or diminishing the make of the furnace.

The hæmatite ore being found in a limestone formation and worked in the district, there is a plentiful supply of good and cheap limestone. That used at Askam is obtained from a neighbouring quarry at Stainton, and has the following composition;—

ANALYSIS OF STAINTON LIMESTONE.

Carbonate of lime	95·00	per cent.
Carbonate of magnesia	4·20	„
Silica	0·50	„
Oxide of iron, and alumina	0·30	„
	100·00	„

The coke used in the Furness district is almost entirely obtained from the Durham coalfield, and is usually of the very best quality. The average composition of the coke used at Askam is as follows;—

ANALYSIS OF DURHAM COKE.

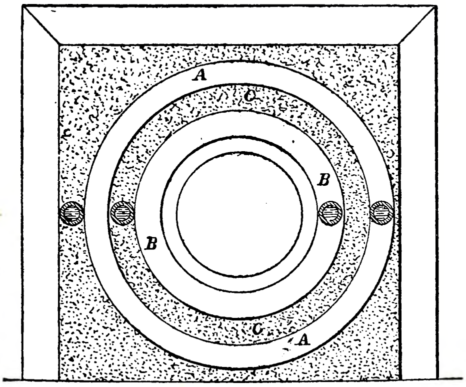
Sulphur	0·70	per cent.
Ash	5·00	"
Moisture and loss	0·92	"
Carbon by difference	93·38	"
	100·00	"

In working a material so difficult to deal with as the hæmatite ore, the first and most important point to be attended to is the proper distribution of the materials in the furnace. In the open-topped and semi-closed furnaces this is easily done by keeping the furnace always full to the same height, and putting in small charges in regular rotation. In the case of close-topped furnaces the same object is accomplished, either by taking care to have the charging bell properly proportioned to the diameter of the furnace, or else by gauging at frequent intervals with an iron rod, in order to make sure that the materials shall never be above or below the height which has been proved by experience to give the most satisfactory results. The gauging must be done not only at one but at various points round the circumference of the furnace, as it is found that there is a tendency at times to drive unequally on different sides; and this may be counteracted by regulating the supply of blast by means of a valve fixed to each tuyere. It is also necessary to prevent the ore being charged in too large pieces; otherwise it is found excessively difficult, owing to the compact nature of the ore, to ensure its perfect reduction before it reaches the part of the furnace at which it is melted.

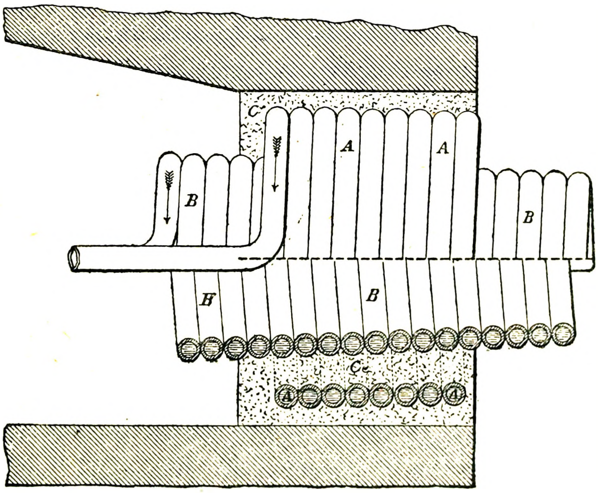
A further difficulty is met with in keeping the tuyere breasts good, as any fretting at these places leads to the necessity for changing the tuyeres, and consequently occasions irregularity of working in the furnace. To obviate this as much as possible, the construction of tuyere and tuyere-breasts shown in Figs. 1543, 1544, has been adopted at Furness, consisting of a close double coil of water pipe; the large outer coil A A is 14 inches diameter and of the depth of the tuyere-breast, and in the centre of it the tuyere B is packed with clay C C; in the event of the tuyere leaking, it can then be easily removed by taking out the clay, and another tuyere can be substituted, the whole process of changing the tuyere occupying only from ten to fifteen minutes. As nothing interferes so much with the regularity of working of a blast furnace as trouble with the tuyere-breasts and changing the tuyeres, this plan has proved to be of considerable value in removing those sources of difficulty.

The result of the working of the Askam No. 2 furnace, of 67 ft. height, 19 ft. diameter, and 13,100 cub. ft. capacity, has been found to be a consumption of $22\frac{3}{4}$ cwt. of coke a ton of iron made when working on Bessemer iron and using the Askam ore mixed with about 10 per cent. of black nodular ironstone, known as Fisher's Red Bay ore, and fluxed with $9\frac{1}{4}$ cwt. of limestone a ton of iron made. The average temperature of the blast during a considerable period of observation was 934° F., and that of the escaping gases at the furnace top about 712° F.

1543.



1544.



The composition of the escaping gases has been found by analysis after drying them to be as follows, at a time when the temperature was 732° F., and that of the blast 968°;—

ANALYSIS OF ESCAPING GASES FROM ASKAM BLAST FURNACE.

	By Volume.	By Weight.
	per cent.	per cent.
Nitrogen	54·51	52·59
Carbonic oxide	34·97	33·80
Carbonic acid	8·36	13·47
Hydrogen	2·16	0·14
	100·00	100·00

The weight of the escaping gases is 120 cwt. to the ton of iron made, and the quantity of heat carried off by them when escaping at the temperature of 732° F. amounts consequently to 22,669 F.-cwt.-units, one such unit being the quantity of heat required to raise 1 cwt. of water through 1 degree of temperature F. The weight of blast supplied to the furnace is 82½ cwt. to the ton of iron made, which at the temperature of 968° F. introduces into the furnace 19,176 units of heat; this is in the proportion of about 85 per cent. of the heat that is carried off by the escaping gases.

The total quantity of heat produced in the Askam furnace by the combustion of the coke and by the blast amounts to 150,000 cwt.-units a ton of iron made, of which 40 per cent. is absorbed in the actual reduction of the iron from the ore, and 15 per cent. is carried off in the escaping gases, the remainder being accounted for by the other operations taking place within the furnace.

The composition of the Bessemer and forge iron made in the furnace, and also of the slag, is given in the following tables;—

ANALYSIS OF ASKAM HÆMATITE PIG IRON.

	No. 1 Bessemer Iron.	No. 3 Bessemer Iron.	No. 4 Forge Iron.
	per cent.	per cent.	per cent.
Carbon, uncombined	3·928	3·377	2·719
" combined	0·109	0·469	1·222
Silicon	2·640	2·424	1·608
Aluminium	trace	trace	trace
Manganese	0·093	0·021	0·021
Calcium	0·021	0·050	0·074
Magnesium	trace	trace	trace
Sulphur	0·004	0·004	0·031
Phosphorus	0·014	0·010	0·016
Iron	93·191	93·645	94·309
	100·000	100·000	100·000

ANALYSIS OF SLAG FROM ASKAM BLAST FURNACE.

Silica	38·00	per cent.
Alumina	10·00	"
Lime	42·19	"
Magnesia	1·65	"
Sulphuret of calcium	2·45	"
Protoxide of iron	2·08	"
Potash	1·60	"
Protoxide of manganese	trace	"
Soda and loss	2·03	"
	100·00	"

The quantity of coke used, 22¾ cwt. to the ton of iron made, is the result obtained in making Bessemer iron, which requires a specially high intensity of heat. The same furnace making forge iron would work well with about 2 cwt. less coke to the ton of iron; and the temperature of the escaping gases has been found to be much lower when this quality of iron is being intentionally produced.

With regard to the opinion that the capacity of the ordinary blast furnace can be increased materially by increasing the height, I. L. Bell, in his 'Researches on the Chemical Phenomena of the Blast Furnace,' arrives at the following conclusions;—

Two great improvements in the smelting of iron were considered by Bell, namely, the use of heated air, and the increase of size in furnace. In point of reputation, the hot blast occupies by far the more important position; but it will be seen from what has preceded that in point of real merit, so far as economizing fuel is concerned, Neilson's discovery is not entitled to this distinction, which is one it has acquired from priority of introduction, and from a supposed virtue believed to be the peculiar property of heated air.

These observations are at present limited in their application to the stage to which Bell's inquiry has been brought, which consists in having proved that, in the matter of fuel consumption, a 71-ft. cold-blast furnace performs as perfectly as one driven with heated air, having an altitude of 53 ft. The 53-ft. hot-blast furnace, it is true, turns out a larger make of iron than that blown with cold air, probably 200 tons a week against 120 tons, but on the other hand, the latter, without any apparatus to maintain or fuel to expend for heating the air, is able to do its work as efficiently, in point of fuel consumed in the furnace, as the other, assisted by the more complicated appendage suggested by Neilson.

It now remains to consider the prospect there is of constructing a furnace so large as to dispense altogether with the use of hot air, without a sacrifice of fuel used in the furnace itself; afterwards to examine the effect of uniting the benefit derived from a high temperature of blast with that obtained by enlarged capacity; and then to test the belief expressed by many smelters that the blast cannot be made too hot for economical purposes, and that real progress in iron smelting must henceforth be looked for chiefly in that direction.

The first portion of this inquiry has been already answered in showing that 25½ cwt. of coke are capable of evolving 93,000 cwt. heat units, the estimated number of units required for producing a ton of pig iron from an ore yielding 40 per cent. of cold blast for 27½ cwt. of coke; and forge iron, in 1834, according to Dufrénoy, was smelted in France with 25 cwt. before the use of hot air was suggested by Neilson.

This reduction of 12½ cwt. was, at Lilleshall, effected upon an ore only requiring, in a 53-ft. furnace, 40 cwt. of this combustible. Whether it would be possible to force the air conveniently through a column of material so high as to be able to produce a ton of pig iron from black-band with 25 to 27½ cwt. of coke with cold blast is a question which would demand consideration. This doubt arises from the circumstance that this variety of ironstone, parting with its oxygen so slowly, consumed in a low furnace 60 cwt. of coke a ton of metal, and would therefore obviously demand a much larger addition to its capacity to bring its coefficients of fusion and reduction into harmony with each other, than an ore only taking 40 cwt. to smelt it under the same conditions as to temperature of blast.

There remains to be considered, a furnace sufficiently large to enable the ascending gases to divest themselves of their sensible heat, and to become saturated with oxygen, both operations, it will be assumed, being effected to the extent permitted by the nature of the process. Suppose, now, into such a furnace, instead of cold air, the blast was admitted at a temperature of 485° C. (905° F.), the same effect in point of increase of intensity would follow as happened when the blast was changed from cold to hot in the lesser furnace, and some of the extraordinary consequences supposed to be due to this additional intensity of heat in the hearth should manifest themselves, if the value of the hot blast were dependent thereon. Such, however, is not the fact; for the furnace, having now sufficient capacity to permit the two functions of fusion and reduction to proceed, in point of time in unison with each other, instead of one heat unit in the blast doing the work of three or four previously evolved by the fuel, each unit of heat thrown in with the air does no more duty than one unit produced by the combustion of coke in the inside of the furnace.

There is no doubt with combustible matter of the same commercial value, it would be much simpler to obtain the necessary heat by the direct action of the blast on the fuel in the hearth of the furnace. Inasmuch, however, as the air is now heated by the escaping gases, or by coal of little worth, there is, in spite of the law just enunciated, a notable advantage in the source of heat rendered available by Neilson's invention. The question, therefore, which presents itself is the extent to which it can be substituted for that generated by the more expensive description of fuel used in the furnace itself.

The chemical laws relative to this, which regulate the power of carbonic oxide to deoxidize an ore of iron in presence of a gas having a contrary tendency, such as carbonic acid, impose a limit to the substitution of mere heat for heat accompanied by the carbonic oxide, the generation of which served as its source. The quantity of carbonic acid due to the reduction and carbon-impregnation of an ore of iron is that represented by 6·58 cwt. of carbon for each ton of metal. It may be assumed that, if the volume of carbonic acid materially exceeds 45 volumes to 100 volumes of the lower oxide of carbon, reduction is nearly suspended. In practice, however, it may be regarded as difficult, if not impossible, to saturate the gases with oxygen to an extent even to obtain this relation between the two oxides of carbon, owing to the slowness of the operation. As a rule, when the gases contain for 100 volumes of carbonic oxide 40 volumes of carbonic acid, it may be assumed that the process approaches the extreme limit to which, in treating the ironstone of Cleveland, it can be carried. When the gases have absorbed a quantity of oxygen sufficient to establish the relations just mentioned, the weight of carbon consumed will be that represented by 21 to 21½ cwt. of good Durham coke. When this quantity of such coke is burnt to the condition of oxides in the proportions mentioned, the heat evolved is not sufficient to discharge the demand made upon it in smelting a ton of iron from Cleveland stone; and the deficiency is exactly represented by the quantity of heat usually contained in the blast at any well-appointed furnace on the banks of the Tees. In other words, if 25½ cwt. of coke, burnt under favourable conditions, can smelt a ton of iron with cold air, 4 cwt. of such coke can be saved if into the furnace a quantity of heat can be introduced with the blast representing 4 cwt. in question.

Supposing, however, that instead of being content with the blast being heated just enough to afford an economy of 4 cwt., which would be about 905° F., its temperature is raised, say to 1472° F. This addition to the heat resources of the furnace will immediately be felt all over its contents; and as soon as it reaches the zone of reduction, where the temperature is such that the carbonic acid therein generated is inert on carbon, this condition of things experiences a complete change, and the superheated carbonic acid now dissolves coke, which is productive of loss, both from the cooling effect of the reaction and from the actual diminution of fuel arriving for combustion at the tuyeres.

Bell has proved this by repeated analyses, and he has invariably found, that just as any excessive quantity of heat was injected into the furnace with the air it received, so did there disappear a quantity of carbonic acid from the gases, corresponding exactly with the needlessly high temperature conferred upon the blast.

The solvent power, as it were, of the gases over oxygen having reached its limit when 30 per cent. of the reducing carbonic oxide has passed into the higher state of oxidation, is a barrier to further economy, because reduction then practically ceases. If, however, reference is made to the table of heat appropriation in Bell's work, it will be perceived there is a loss of nearly one-tenth of that evolved by the sensible heat carried off in the escaping gases. Appreciable as this is, it is less by one-half from a furnace of 12,000 cubic feet than it was from one of 6000 cubic feet.

Spiegeleisen is a pig metal which breaks into mirror-like facets, and was formerly produced by charcoal out of manganiferous iron ores, its singular peculiarity being due to the presence of 10 to 12 per cent. of manganese, on which the Bessemer process depends for its success. The hot-blast furnaces formerly employed in Germany for the production of this variety of iron were of small outlines, but always in working condition. The stacks of the well-known Müsen Stalberg Ironworks, and others in that vicinity, were thus built;—Total height of furnace, 35 ft.; height of tuyeres above bottom, 1 ft. 3 in.; height of hearth, 5 ft.; height of boshes, 9 ft. 5 in.; diameter of tunnel head, 3 ft.; diameter of boshes, 9 ft.; diameter of upper part of hearth, 2 ft. 8 in.; diameter of lower part of hearth, 1 ft. 11 in. They were worked with hot-blast air at about 300° to 480° F., the air being forced into the furnace through two tuyeres of $2\frac{1}{2}$ to $2\frac{3}{4}$ in. diameter, at a pressure of $1\frac{1}{4}$ to $1\frac{3}{4}$ lb. a square inch. The average consumption of charcoal to the 100 lb. pig metal was about 118 lb. to 120 lb.; the average daily production during the year, about $4\frac{1}{2}$ tons. In the practical working of the furnace the spathic ores yielded about 38 to 30 per cent. of iron. But on account of the devastation of the forests, and of the scarcity of hard wood suitable for conversion ino good charcoal, this fuel, soon after 1859, proved insufficient to produce the spiegeleisen wanted, and it became necessary to replace the charcoal by coke.

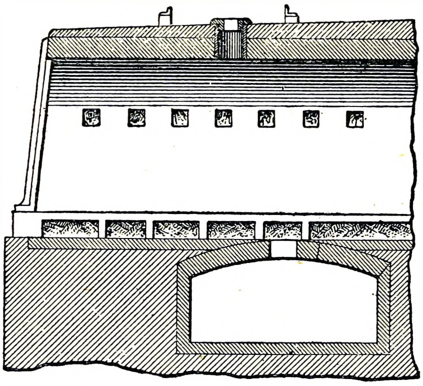
In Rhenish Prussia there are a number of blast furnaces, each producing daily some 30 tons of this valuable and peculiar pig metal. The iron ores used are of four different kinds;—

Red hæmatite, a very pure ore from the beds existing on the Lahn, a large tributary of the Rhine at Nassau. Of this ore there are two varieties, a harder and compact mineral associated with a calcareous gangue, and a softer and pulverulent hæmatite. Both varieties are entirely free from sulphur and phosphorus, containing from 3 to 4 per cent. of manganese, a small percentage of alumina, water, and silica. The presence of carbonate of lime in the body of the compact ore gives it a peculiar character, and renders it eminently fitted for mixing with other siliceous ores, there being in the ore 50 per cent. of iron and from 10 to 15 per cent. of carbonate of lime. This ore is very economic in smelting, owing to the presence of lime flux in the most favourable conditions. The soft, pulverent ore is richer, yielding 55 to 58 per cent. of metallic iron in the practical working of the furnace. Both kinds are easily reduced.

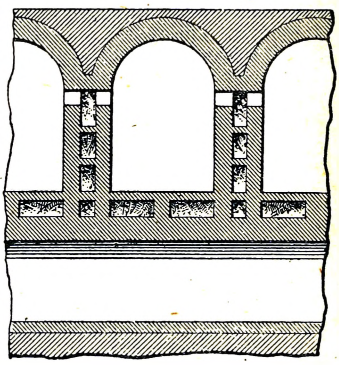
The products from decomposition of the specular ore, of similar favourable constitution, and equally free from obnoxious mixture. It contains some water chemically combined $(2Fe_2O_3,3HO)$, is porous in structure, yields about 50 to 54 per cent. of iron, and is more easily reduced than any other ore.

Excellent spathic iron ore from the vicinity of Müsen, in which a certain proportional part of the iron, from 8 to 14 per cent., is replaced by manganese. All the spathic ores (FeO,CO_2) contain a trace of sulphur, and therefore require calcination. The calcination is effected in kilns, Figs. 1545, 1546. In these roasting furnaces, by distributing it in alternate layers with waste coal, the ore is rendered porous, and easily broken into small pieces, whereby it is more easily acted upon in the smelting furnace. The chemical constitution of the ore in the crude state is $MnO,CO_2 + 4FeO,CO_2 =$ oxide of iron 49·01; oxide of manganese, 12·43, carbonic acid, 38·56. The oxide of iron represents 37·85 per cent. of metallic iron. By the calcining process the ore is changed into, sesquioxide of iron, 81·89, representing 56·78 metallic iron, and sesquioxide of manganese 18·11 per cent.

1545.



1546.



An aluminous ore is used for admixture with the others to make a liquid slag. These deposits of ore are from 80 to 100 miles distant from the works, and are easily accessible by navigation and by rail.

The flux used is a very pure carbonate of lime, the constituents of which are, carbonate of lime, 98·00; silica, 1·50; hygroscopic water, 0·50. As a reducing agent coke is used, the bituminous coals being purified prior to their application to the blast furnaces. The coals are from the vicinity of the ironworks, and the ores are brought thither, for it is always cheaper to bring the iron ores to the coal than the coal to the ores. They contain a good deal of slate, and from 5 to 1 per cent. of sulphur, and to eliminate these noxious adherents they are subjected to a very careful process of grinding to the size of a hazel nut, and separating by means of water. Having been subjected to this process, the coals are coked in close furnaces, Figs. 1545, 1546, the charge of each furnace consisting of 120 bushels, covering the bottom of the furnace to a height of 18 or 20 in. The coking process lasts thirty-six hours, and furnishes from 57 to 60 per cent. of coke by weight, of porous cellular character sufficiently firm to hold up the burden of the furnace, and containing 8 to 10 per cent. of ashes of a reddish-white or grey colour. The volatile carbonic matter of the coals, after having been used to heat the partitions and floors of the coking furnaces, are sufficient to heat the steam boilers. The air blast is supplied by two 80-horse horizontal engines, maintaining four blast furnaces, and one vertical 100-horse engine for fifth furnace and for reserve. The blast is regulated by being passed through a reservoir 200 ft. long and 6 ft. diameter = 4654 cub. ft. The principal dimensions of the horizontal engines are—diameter steam cylinder, 3 ft. 3 in.; diameter blast air cylinder, 7 ft. 6 in.; length of steam cylinder, 6 ft.; each revolution of the fly-wheel would therefore give 1060 cub. ft. only; 18 or 19 revolutions a minute, allowing 12 per cent. for loss by leakage, 16,800 cub. ft. The vertical engine has—diameter of steam cylinder, 3 ft. 3 in.; length of cylinder, 7 ft. 9 in.; diameter of blast-air cylinder, 8 ft. By 13 revolutions a minute there will be 18,000 cub. ft. of air, less 10 per cent. for leakage. Before being forced into the furnace, the blast air is heated by means of the gases escaping from the mouth of the furnace and collected there by means of a special apparatus. It is found that two heating apparatus of the form Figs. 1547 to 1549 are sufficient to heat the blast air of each furnace. There are fifty-two pipes in each apparatus of the shape represented, each pipe being divided, by means of a partition, into two parts, so that the blast air may ascend and descend in each. The latter are from 10 ft. to 12 ft. long, the surface exposed to the fire is 2429 sq. ft., and the cubic contents of the fifty-two pipes 460 cub. ft.

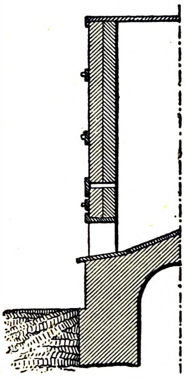
The dimensions of the blast furnaces Figs. 1550, 1551, there being two groups of stacks, are;—

DIMENSIONS OF SPIEGELEISEN FURNACES.

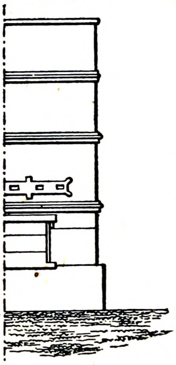
	No. 1.		No. 2.	
	ft.	in.	ft.	in.
Height of furnace	54	0	54	0
Diameter of tunnel head	8	8	9	6
„ „ boshes	15	2	15	3½
„ „ hearth, upper end	4	9	3	11½
„ „ „ lower end	4	9	2	10
Height of hearth	6	3	7	9½
„ „ boshes	11	9	10	3¾
„ „ centre of tuyeres above bottom	2	5	2	5
Inclination of the boshes, 50°	..		..	
Square contents of the mouth	59	0	72	0
„ „ „ boshes	180	0	183	0
Cubic contents of the whole furnace	6396	0	5910	0

The bottom and lower parts of the hearth, up to 3 ft. above the tuyeres, are built with puddingstone from Marchin, in the Ardennes, Belgium; and for the upper-hearth boshes and tunnel of the furnace, Ardennes fireclay bricks are used. It must be remembered that spiegeleisen is chemically composed of four parts iron with one part carbon Fe_4C, and that the combination is only formed during the period of the smelting process which follows immediately after the deoxidation of the iron ores. To fulfil the conditions under which this combination of iron and carbonic matter can take place, it is absolutely necessary that the mixture of ores and flux be of the most fusible nature, so as to allow of the accumulation of the charge, in proportion to a fixed amount of coke, to such a degree that the smelting and separation of the iron from the slag occurs at a point as near as possible to the tuyeres. It is safe to say that this separation, when resulting at a higher place in the hearth, would give too great an opportunity for the carbonic acid gas to carry off some of the carbonic matter from the iron, changing itself into carbonic oxide, and reducing at the same time the constitution of the spiegeleisen, Fe_4C, to a lower grade of carbonization. The temperature at which the specular iron melts is calculated = 3582° F. It is therefore found necessary that the charges should be composed of red hæmatite, 30 per cent.; spathic ore, 38 per cent.; decomposed brown ore, 20 per cent.; and aluminous ore, 12 per cent., yielding 40 to 50 per cent. metallic iron in the practical working of the blast furnace, and to create the needed fusible slag there was added from 32 to 40 per cent. of lime. Each charge consisted of 1860 lb. coke, 2800 to 3200 lb. of mixed ore, and 800 to 960 lb. of carbonate of lime. The furnace carries thirty-five to forty charges in the twenty-four hours, and yields an average of 60,000 lb., or 30 tons a day. For 1 ton of pig metal there was used 2 tons of iron ores, nearly 13 cwt. of fluxing materials, and 1¼ ton of coke. The blast air, with a temperature of 630° to 660° F., is forced into the furnace at a pressure of 2½ to 3 lb. a sq. in. at the engine, and of 2·2 to 2·6 at the tuyeres. Out of the five tuyeres, Fig. 1551, two are on opposite sides and one at the rear of the furnace; each one declined a few degrees from the centre of the hearth, so as to force the blast air into a kind of whirlwind, which is considered the best way of distributing the compressed air through the smelting and combustible mass.

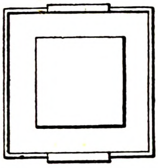
1547.



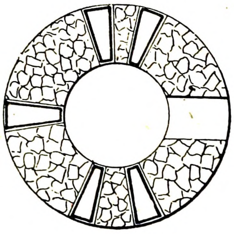
1548.



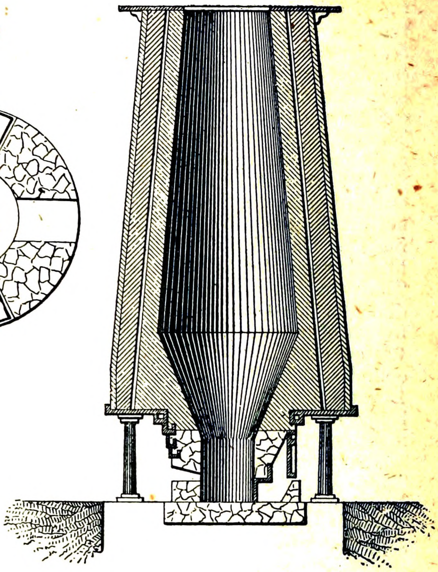
1549.



1551.



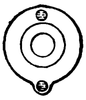
1550.



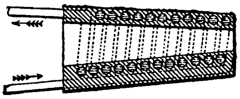
The dimensions and shape of the tuyeres for the blast furnace vary greatly in different districts; but until recently all the tuyeres in use, since the introduction of hot blast first necessitated a water tuyere, may be classed under two heads, the coiled tuyere and the water-jacketed tuyere.

The coiled tuyere is generally made of a coil of wrought-iron tube imbedded in the sides of a hollow cone of cast iron. Sometimes the coils are wound close at the nose of the tuyere, in order more effectually to prevent the cast iron from burning; and sometimes the tuyere itself is formed entirely of a coil of tube, closely wound from end to end. This form of tuyere is illustrated in Figs. 1552 to 1555, Figs. 1553 and 1555 showing the coil in section.

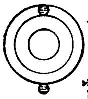
1552.



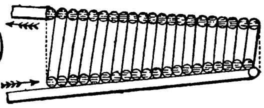
1553



1554.

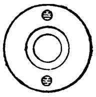


1555.

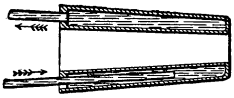


The water-jacketed tuyere is generally made of wrought iron, and consists of two conical tubes of different diameter, connected at each end by rings of wrought iron welded in, so forming a space between the two concentric walls of the tuyere, which is filled with water supplied under pressure, and generally brought in through a feed-pipe at or near the bottom of the tuyere, and allowed to escape through a second pipe in the upper side. Figs. 1556 to 1559 are tuyeres of this description; Fig. 1557 the ordinary wrought-iron tuyere, and Fig. 1559 the gun-metal tuyere introduced by Solly.

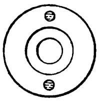
1556.



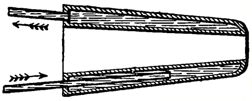
1557.



1558.



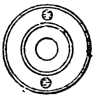
1559.



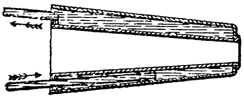
A water-jacketed tuyere, Figs. 1560, 1561, is very much used on the continent of Europe; it is made of wrought copper, the inner tube being brazed in, and a wrought-iron ring either brazed or riveted in at the rear end.

Figs. 1562, 1563 are of the phosphor-bronze tuyere. These tuyeres are generally fixed in a cast-iron casing, beyond which they project into the furnace for the greater part of their length, and they are so arranged that they can be turned round in the cast-iron plate in order to expose a different side of the tuyere to the action of the materials in the furnace. Greater durability is claimed for phosphor-bronze than for gun-metal or copper, but each metal possesses the same advantage of preventing the adherence of slag, scoria, or iron to the nozzle of the tuyere, which is the only object to be gained by the use of copper or its alloys in preference to iron. Additional precautions as to water supply have to be taken where such metal is used, as owing to the low temperature at which it melts, a tuyere may be more rapidly destroyed than an iron tuyere where any over-heating is possible; but under favourable conditions gun-metal, copper, and phosphor-bronze tuyeres have all been found very durable, and the advantage gained by keeping the blast nozzle always clean and fully open is an important one.

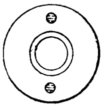
1560.



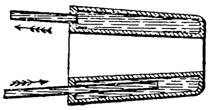
1561.



1562.

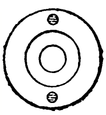


1563.

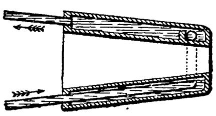


Figs. 1564, 1565 are a modification of the wrought-iron water-jacketed tuyere, introduced by Hodgetts, in which the supply pipe is made to deliver its water round the nose of the tuyere through a series of perforations, and the return water is made to flow round the tuyere casing by a fillet placed on the inner tube. This tuyere, like the ordinary water-jacketed tuyere, is close at the back, and is kept full of water.

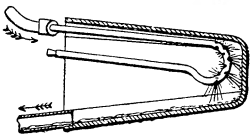
1564.



1565.



1566.



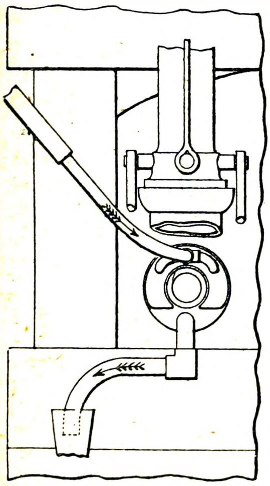
The Open Spray Tuyere, invented by F. H. Lloyd of Wednesbury, to whose paper in the 'Trans.' I. M. E. we are indebted for much of our information on this subject, is shown in Figs. 1567, 1568, with the blast pipe connected; in the side view, Fig. 1566, the blast pipe is broken off.

It consists of two concentric conical tubes, closed at the nozzle, but open at the rear end. The water supply is connected in the usual manner with a flexible hose, and various systems of spray pipes are used to suit various shapes of tuyeres and conditions of water supply.

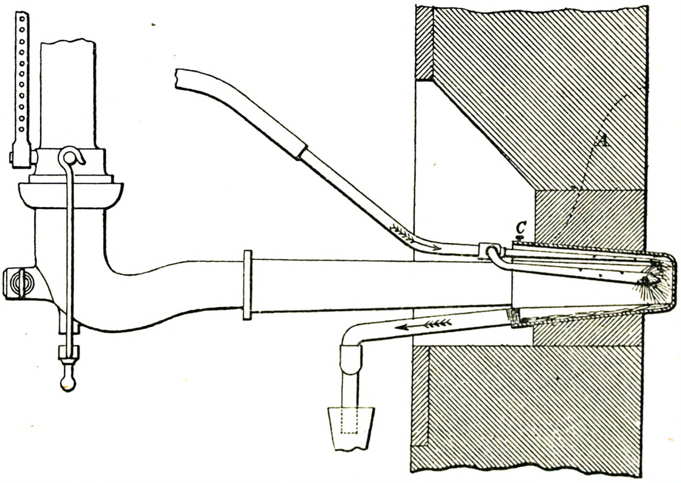
Although iron spray pipes are now extensively used, they are liable to rapid corrosion; and the use of brass or copper pipes is found to be an improvement. A set-pin may be used, as at C, to prevent the spray pipes being accidentally displaced. It has been found advantageous to turn the nozzle of the tuyeres in some cases; by this means the adherence of scoria, or what is commonly known as ironing, is to a great extent prevented, and the tuyeres are thereby rendered more durable.

The spray pipe, Figs. 1567 and 1568, consists of three tubes slightly flattened towards the point, and in some cases shaped or bent to suit the shape of the tuyere. These three tubes are joined by a wrought-iron fitting, which is connected by a fourth tube with the water supply. The spray pipes are made either of wrought iron, brass, or copper, and a sufficient amount of water is allowed to escape through small holes or slits in the pipes, to protect every part of the tuyere casing which is exposed to the heat of the furnace. In Fig. 1566 the spray pipe is shown with the two side pipes bent back and plugged at the ends with wooden plugs, which may be removed occasionally if it is thought desirable to clear the spray pipe from any sediment. The spray or jet of water

1567.



1568.



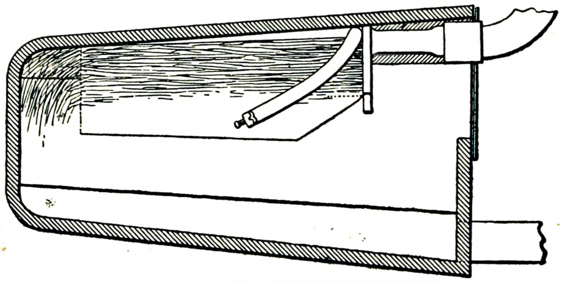
from each hole in the spray pipe spreads over a considerable surface, and a small number of holes is, if they are properly placed, sufficient to keep the whole interior surface of the tuyere casing constantly wet. Scarcely any steam is visible, and the waste water passes away, after cooling the tuyere, at a temperature little exceeding that at which it entered, unless a large portion of the tuyere is exposed to violent heat. The spray is principally directed to the nose end of the tuyere, and beats back to some extent on the top and sides, which are also protected by a sufficient number of additional sprays from holes drilled in the pipes. The water falls round the sides and ends of the tuyere, and escapes from the back at the bottom through the waste-water pipe.

The durability, however, of these tuyeres is not their main advantage. Like all others, any derangement or choking of the water supply will cause them to burn out; and in common with all other tuyeres they are liable to some of the accidents which will be referred to. If, however, a small hole be made in the side or end of the tuyere, either from stoppage of water supply, or any other cause, it is still impossible for water to escape into the furnace. Frequently a tuyere that is heating may be saved by shaking or adjusting the spray pipe; but even if the end of the tuyere is entirely burnt, it is still impossible for water to flow into the furnace, as the blast will at once escape through any aperture, be it small or large, and consequently blow back any spray through the open end of the tuyere casing. If the hole is small and the damage is detected in time, the adjustment of the spray pipe will often cause it to iron up. If too large for this, there is still no necessity for haste in removing the tuyere, as the escape of blast through the aperture drives back the spray and prevents the possibility of any harm or danger, such as would result from the fall of this water into the furnace.

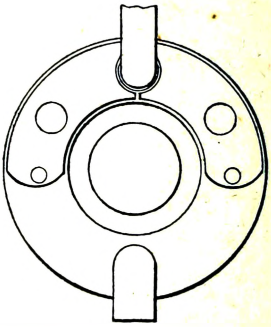
When a spray tuyere is damaged, it can generally be repaired after removal by welding a small piece of iron on the damaged part; or in the case of gun-metal or copper tuyeres, a piece may be tapped or brazed in and the tuyere made as good as new, at a very trifling expense.

The Spreader tuyere, Figs. 1569 to 1572, has a water jacket, and the outer end is only partially closed at first. The lower half, Fig. 1569, is closed by a fixed half ring welded to or cast with the shells; the upper half is afterwards closed by a movable piece as at Fig. 1570; sight holes are provided for the convenience of examining the condition of the tuyere, which, being so far closed, besides giving greater facility for detecting overheating, enables the clay packing to be done with as little care as with the ordinary tuyere.

1569.

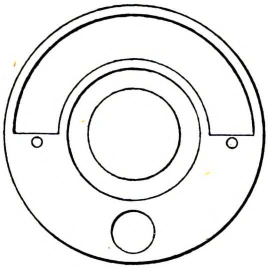


1570.

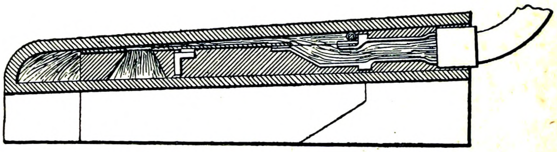


The water supply is furnished in the usual manner until it enters the tuyere, where through a specially prepared pipe, Fig. 1572, it is conducted to and over a sheet-metal spreader that holds up a constantly flowing sheet of water against the upper half of the outer shell of the tuyere; from the end of the spreader, a fan-shaped jet of water is delivered against the nose end of the tuyere, and a stream down each side of the outer shell, thence flowing towards and through the outlet pipe; the force with which the water is ejected against the nose of the tuyere depending upon the pressure available, the distance of the end of the spreader from the nose of the tuyere, about 2½ in. in Figs. 1569 to 1572, being regulated accordingly. Where there is but little or no pressure, the spreader is continued close up to the nose-end of the tuyere, thereby conducting the water effectively against it.

1571.



1572.



In addition to the complete freedom from the danger of explosion, and from the liability of water getting into the furnace, which this mode of water-cooling gives in common with, but in no degree superior to, the open spray tuyere, the Spreader tuyere is comparatively free from the liability to be burned from scurfing and other obstructions, arising from bad water, and is readily relieved should such an impediment in any degree happen; a very slight movement of the spreader to and fro, suffices to rub off and flush away accumulation without interrupting the water supply, and if requisite, the spreader can be entirely withdrawn, cleaned off, and replaced in a minute or two.

To remove ordinary bronze tuyeres, it is only necessary to insert a hook and pull them out, while this operation is retarded with iron tuyeres by the tenacity with which dropping iron adheres to them. The remedy used by some, of digging the iron tuyeres out, partly at least, while the blast is still on, is dangerous, as the men engaged in it have been seriously injured by their blowing out. Bronze tuyeres, too, have proved the best for the highly heated blast coming from firebrick stoves.

The causes which may lead to the destruction are varied and numerous. Foremost among them is deficiency of water supply or obstructions to its free circulation, such as muddiness of the water, imperfections of the screens, insufficiency of the size of the pipe and its attachments and fittings. Another serious and too frequent source is drilling of the tuyere by dropping iron and slips of the furnace. In order to ensure sufficient water supply, each 1-inch pipe attachment should be allowed 10 gallons a minute, an amount which will cool 230 sq. in. of exposed tuyere surface, with a minimum pressure of 10 lb. a square inch. Muddy water should be avoided, if possible; but where it must be used it should enter at one end of the tank and be taken off at the other end. A good plan is to collect the tuyere water in a collecting pond, and allow it to cool before using it again. Screens must be large, and must be made amply strong, to resist any collapsing caused by the meshes getting filled and being drawn together by the descending current of water. The supply pipe to the tuyeres should come up through the bottom of the tank 16 in. Over it a strong cylindrical screen, with meshes $\frac{1}{12}$ in. square, made of brass wire, should be slipped. The lower end of the screen should terminate with a heavy iron ring, projecting 2 in. out from the screen, acting as a base. The top of the screen should end near the level of the water, and have a handle to lift it up. Outside this screen must be placed another cylindrical screen, the internal diameter of which is a little larger than the collar or ring of the inner screen. This screen is of brass wire $\frac{1}{2}$-inch mesh, and is well stayed. The screens can be taken out one at a time, and cleaned, without allowing any floating matter to reach the tuyere pipe. The area of meshes of the inner screen must be five times that of the main or tuyere pipe. Large pipes must be used from the tank to the tuyeres, in order to keep up the head. No other attachment should be allowed. If the tuyere pressure is short, the circulation of water will not carry off the heat from the metal of the tuyere rapidly; this will allow a bead or bubble of steam to form on the inner surface, which holds to the metal, and is retained in place in a spherical form by the pressure on it. This bubble increases in size until the expansive force of the steam within the bubble bursts it. The water then rushes in to fill its place. During the time the bubble is forming, the metal of the tuyere has been growing hotter, and therefore instantly another bubble is formed, which allows the temperature to rise higher. This accumulation goes on until the steam is powerful enough to back the water, and then the tuyere burns. With a proper circulation, this is avoided. In many cases the pig-bed hose is attached to the tuyere pipe, and as it is used frequently the head of water is lowered, and often at a time when there is danger of the tuyere burning. In such a case, of course, it is destroyed. A mud deposit may be easily washed out of the tuyere if provision has been made for the emergency by putting a plug into the large end. The ordinary plug cock should not be used on the tuyere connection, because the hole in the plug, when partly closed, is a long, narrow slit, and catches everything that comes along. A plug with a round hole is best, as it still preserves a good-shaped opening when partly closed. It is well to open these cocks once a day for a few seconds.

Drilling is caused by iron melting above the tuyeres; it cuts grooves into the lining, and directs the current of iron on one spot of the tuyere. This drilling is worse if the furnace is working irregularly, as the stock in the centre of the furnace deflects the blast and heat against the walls, thus causing the melting at that place instead of evenly throughout the whole mass. Tuyeres should not project far into the furnace, as they are more liable to be drilled and to be burned, from the metal collecting around them at times during irregular working. In order to obviate the necessity of projecting the tuyeres far into the furnace, for the sake of getting the blast further into it, the size of the tuyere nozzle should be regulated. Little attention has been paid to this in the past, for two reasons, on account of the difficulty in preventing the nozzles from burning off, and on account of the time and trouble required to change nozzles. Another cause of drilling may occur after casting, when the blast is off the furnace, in the following manner;—A piece of coal may get crosswise into the mouth of the tuyere, deflect the dripping iron into it, and drill it on the inner bottom surface. Bronze tuyeres stand the drilling better than iron ones, as the high conducting power of the metal instantly chills the hot drop. In a comparative test recently made, a furnace was tried with bronze tuyeres on one side and iron coil-tuyeres on the other side. As the furnace was drilling its tuyeres badly, the test was a good one. The result proved that the bronze tuyeres lasted three times as long as the coil tuyeres. The same results have been obtained at other places.

Water breasts are useful in such a case; they are short tuyeres which are built into the breasts of the wall. Their cooling action soon builds up a coating on the breast, which protects them. This arrangement possesses some other advantages which recommend it to more universal use. As it is firmly built into the wall, it holds the tuyere in position even when the wall below the tuyere is corroded away by cinder and iron, and prevents it drooping. The old arrangement of sprinkling water on breasts is done away with by the water breasts, and a more effectual method is used. In the event of a slip, it breaks the force of the falling mass, and lessens the danger caused by the metal being forced up around the tuyeres. Nozzles should be so proportioned that an equal volume of air passes through each of them. They should be kept clean and bright. The pricker rod should be used frequently. As soon as a tuyere is dull, and one tuyere pipe is not of the same temperature as the others, as it is a proof that the air is not passing into the furnace through it, a vigorous application of the pricker rod must be made, to break away any crust and get the air further into the furnace in order to reach fresh coal, which will soon brighten it up. It is the neglect of these small matters that leads to larger and greater troubles.

In using coil tuyeres, the nozzle is bedded in the nose in fireclay. During the time the blast is on, the nozzle retains its shape and delivers the air well into the furnace, but when the blast is taken off during the casting, the heat melts the nozzle off about 6 in. from the nose, enlarging it, allowing the blast to expand in the end of the tuyere, and diminishing its penetrating power. The melted iron, dripping down over the nose of the coil tuyere, melts the casing off the nose for four coils back; the air then passes up between the coils, which further disperses the blast and destroys its penetrating power. When the blast escapes through the coil, it starts more melting above it, which ultimately leads to the cutting of the tuyere. When the blast is thus dispersed, it cannot penetrate, but it creates an intense local heat in front of the tuyere which destroys the brickwork of the breasts. With the double jacket tuyeres the air is delivered solid into the furnace, and dispersion is avoided. If a scale or clinker forms over the nose of one or more of the tuyeres, no blast can pass them into the furnace; then more intense combustion takes place before the others, and soon the furnace works on one side. This is more apt to occur with large hearths, hence the necessity of extra vigilance with them. Large hearths greatly influence production. With properly proportioned blowing engines and hot-blast stoves, the hearth determines the production of iron more than the diameter of bosh does.

To show that large nozzles are not required, take a blowing engine giving 10,000 cubic ft. a minute into the open air. This air will pass through an opening of 19 sq. in., which is equal to one 5-in. nozzle. More than this must, however, be allowed in the furnace. Using anthracite and 10,000 ft. a minute, the combined area of the nozzles should not be less than 70 sq. in. On coke this should be more.

The points to be attained are a large hearth with tuyeres kept back, the force of the blast being depended on for its penetrating to the centre, aided by choking down on the nozzles slightly. The action of the blast burns the coal or coke from the front of the tuyere, keeps an opening into the interior, and prevents the formation of a core. Tuyeres should be set 5 ft. from hearth to centre as a minimum; the bottom should be drained well for high tuyeres. The cinder-notch should be not less than 16 in. lower. This keeps the tuyeres free from cinder, bright and clean, and there is less liability of getting iron to them if the iron notch is hard, and casting is delayed thereby. Low tuyeres blow into the cinders and chill them; high tuyeres blow into good clean coal, and keep up the heat of the hearth. When a tuyere burns off, the water enters the hearth, absorbs heat, and lowers the grade of iron.

A cause of destruction to tuyeres, which is readily capable of explanation, arises when the materials in the furnace are so dense as to prevent the blast ascending freely, causing resistance round the tuyeres, destroying the stopping, and leaving the greater part of the tuyere naked and exposed to heat, as indicated by the dotted line at A in Fig. 1568, which under such circumstances is unusually intense round the tuyeres. A close tuyere, fed in the usual manner, when exposed to excessive heat, will sometimes refuse its full supply of water, either from the generation of steam in the tuyere, or from some other cause, and this may cause the tuyere to burn, and thus allow the escape of water into the furnace.

Slips of material after a furnace has been hanging will sometimes destroy or blind every tuyere in a furnace, by the fall of solid material on them or in front of them. Accidents to tuyeres from this cause have not unfrequently occasioned severe explosions. Another cause of injury to tuyeres, and of great danger where close tuyeres are used, arises from the slag, or in some cases the molten metal, rising up to the tuyere level. This may happen from neglect of the workman to open his furnace in time, or from having a hard tap so as to delay the running of the molten metal at casting time. In all cases, it is when damage to close water tuyeres has been occasioned by the rising of metal or slag to the tuyere level, that the greatest danger from the escape of any water into the furnace is to be feared.

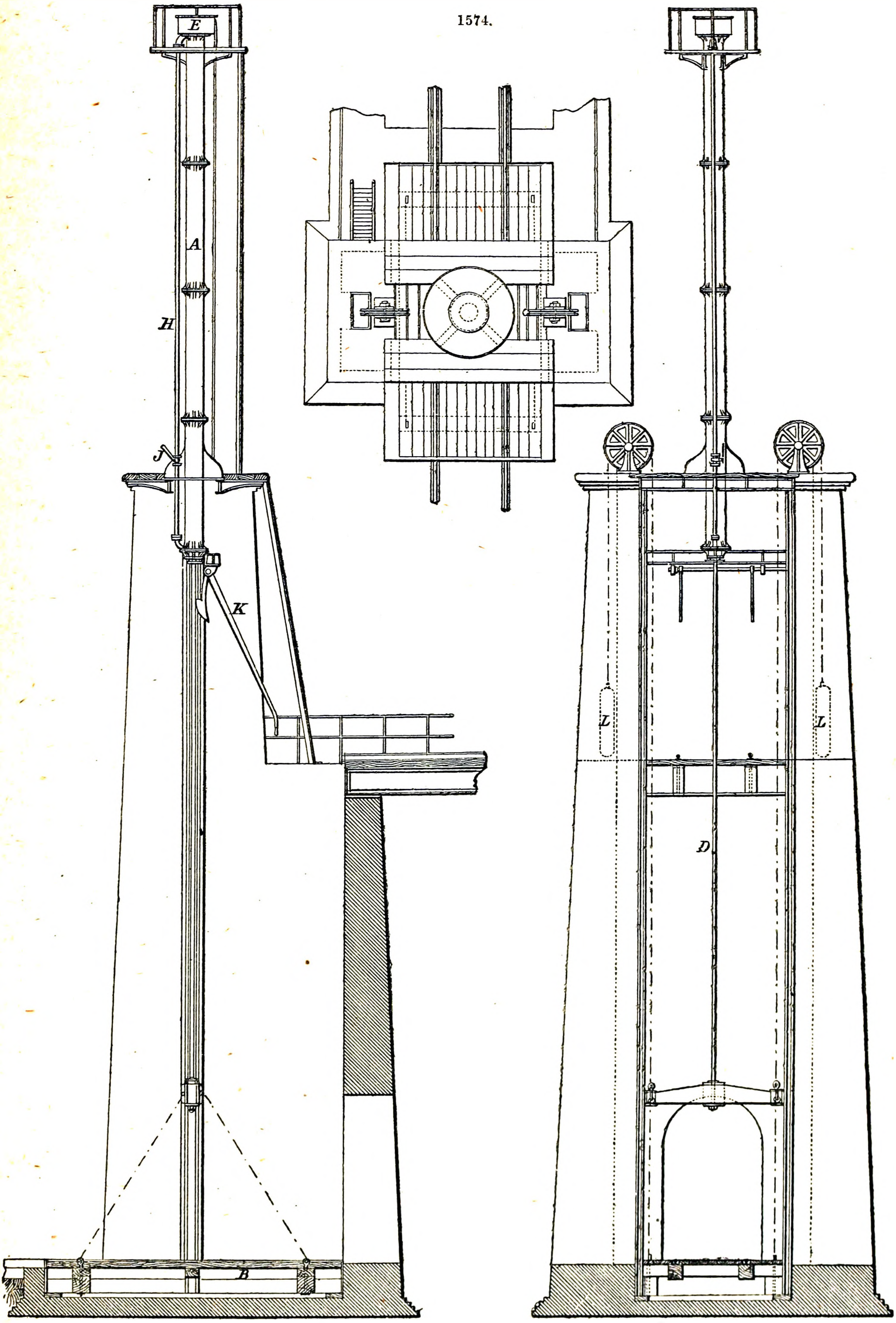
The leakage from a very small hole in a coil or close water tuyere, from whatever cause it arises, will in most cases be evaporated by the heat of the furnace, and cause no further damage than a trifling loss of heat; but the same action that causes a small defect will very often increase the aperture before any leakage can be detected, and when leakage occurs from the lower side of a tuyere, it is not unfrequently difficult to detect by examining the blast opening in the usual manner.

A simple arrangement has been introduced by Thomson of Ruabon for the purpose of detecting leakage when it occurs from any close tuyere. It consists of a water balance, which, so long as the same amount of water flows from the tuyere as is supplied to it, is kept in equilibrium; but the moment any leakage occurs, the equilibrium is disturbed, and by this means a whistle or alarm is sounded. This arrangement is said to answer well, and to give warning when a very slight amount of leakage occurs. The warning, however, even if promptly acted upon, would not in all cases prevent danger, as in the case of the destruction of a tuyere from a sudden slip in the furnace.

In T. Wrightson's Blast-furnace waggon drop, Figs. 1573 to 1576, water is the controlling agent. The cylinder A is of the same length of stroke as the fall of the cage, and may be 10 or 12 in. in diameter. The cage B is attached to the piston C by means of a long piston rod D, working through a stuffing box at the bottom of the cylinder. At the top of the cylinder is a small supply tank E, Fig. 1573, fitted with a self-acting ball-cock, to keep it always supplied from the nearest water main. A small adjustable hole in the cover communicates with the inside of the cylinder to ensure that it is always full of water, and another small hole G, Fig. 1576, in the piston allows any air which may accumulate under the piston to pass to the upper part of the cylinder, where it escapes into the tank by the hole in the cover.

A pipe H connects the top with the bottom of the cylinder, through an ordinary water-cock J, which is controlled by a weigh-bar and lever. A catch-lever K is placed alongside the valve lever, and serves to lock the cage as it comes to the top of its stroke. This holds the cage while the waggon runs on. When the cage with the waggon on is required to descend, the catch-rod is liberated, and then the valve handle is lifted. By the opening of this valve J the water passes from the bottom to the top of the piston, thus controlling the descent of the cage to any speed the attendant may choose. When the cage is at the bottom, a self-acting stop is removed by the action of the cage touching the ground, which allows the waggon to run off at the lower level. The cage

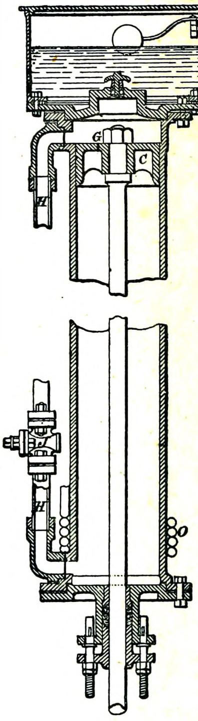
1573. 1574. 1575.



being then lighter than the counter-weights L is drawn up again, the water in the cylinder during the ascent returning from the top to the bottom of the piston. When the cage arrives at the top of its stroke it locks itself, and is then ready for another waggon to be run on.

The bulk of the water passes and re-passes through the cock J, but on account of the area of the piston being less by the area of the piston rod on the lower side than the upper, the water at the top, displaced as the piston rises, cannot find room at the lower side of the piston, and will therefore find relief, by a portion equivalent to the cubical contents of the piston rod, passing through the small hole in the cylinder cover into the supply tank. In the same way when the piston again descends, there would be an equal deficiency in the water passing from the bottom to the top side of the piston; this is compensated by the same amount of water re-passing through the hole in the cover. By this means the cylinder is always kept full of water, which is essential to the successful working of the apparatus. The same water is used over and over again, and the ball valve in the tank is merely to supply any loss from evaporation or leakage. The small pipe O encircling the cylinder, Fig. 1576, is for the admission of steam in frosty weather to prevent the freezing of the water. This comes from the nearest steam or exhaust pipe, and after coiling a few times round the lower part of the cylinder, passes up to the top tank alongside of the connecting pipe.

1576.



As regards the supply of homogeneous iron, and the degree of homogeneity to be expected in iron produced by various systems of puddling and subsequent working, Henry Kirk, Workington, read an important paper on this subject before the Institute of Mechanical Engineers, in 1877, and to this we are largely indebted in the following pages.

Kirk first remarks that the word puddling was originally restricted to the working of refined iron, which never became thoroughly liquid, but was in a puddle or pasty state throughout; and when unrefined pig began to be worked, and was found to melt thin and boil up freely from the rapid escape of carbon, the process was termed "boiling." But as the puddled iron was better than the boiled, there was the temptation to sink the word boiling altogether, and this has been done so completely, that now, when we want to speak of the old puddling process, which is still carried on at all the best Yorkshire works, and at many others where the very highest quality of iron is made, it requires a lengthy description to convey the intended meaning.

The term homogeneous seems to have been first applied to iron about twenty years ago, and it meant a comparatively pure iron manufactured by melting, too low in carbon to be called steel, in fact presenting none of its characteristics. But within the last ten years makers of homogeneous iron have appropriated the term steel, steel being something better than iron; and now there appears in some quarters a disposition to adapt the word homogeneous to iron produced by puddling, whereas puddled iron is not, and perhaps cannot be made, truly homogeneous. It is highly probable that the use of the term steel has very much hindered the employment of true homogeneous iron in works of construction, for which it appears to be eminently fitted, by creating false impressions as to its hardness and the expense of working it, and it is a question whether the appropriation of the term homogeneous will help iron manufacturers nearly so much as the closest approximation to its most valuable properties which it is in their power to make. But here arises a difficulty: the finely crystalline appearance of such iron, when cut round with a chisel and broken suddenly off, finds little favour with engineers, while the fact of its being remarkably strong in its hot as well as in its cold state, and requiring a good deal of fire to heat and muscular force to work, excites prejudice on the part of those who have to expend their labour upon it.

Homogeneous iron is considered here as iron of the same kind or nature throughout, and consisting of similar parts; thus iron may be homogeneous and yet contain all the elements usually associated with it, such as carbon, silicon, sulphur, phosphorus, and manganese; but iron containing cinder cannot be truly homogeneous, because the nature of cinder is altogether different from that of iron, and in fact cinder does not combine with it at all, but only remains diffused throughout the mass. Iron produced by melting and casting into solid ingots, carefully heated and well worked, may properly be called homogeneous. Such iron has no right to the term steel when the carbon is not above 0·30 per cent., which is an amount sometimes exceeded in the very best brands of wrought iron; for instance, an analysis of Swedish iron is given by Percy with 0·386 per cent. of carbon, and one of Russian with 0·34 per cent.

Homogeneous iron, or mild steel as it is now called, is remarkable, as compared with puddled iron, for its high degree of strength and ductility combined. This is well exemplified in the samples of mild steel and iron hoops of which tests are given in Table I. The pieces were about 6 ft. length each, and the testing machine was one specially constructed for ascertaining the tensile strain and ductility of telegraph wire. Considered superficially the steel appears twice as good as the iron, taking strength with ductility; but when it is considered that to obtain the comparative value for work, say by Mallet's coefficient, half the breaking weight has to be multiplied by the elongation a foot, it will be seen that the steel has about 4 times the value of the iron. This, however, does not exhibit the whole of the difference between the two. By the same rule of calculation, No. 16, the lowest of the steel, gives nearly 12 times as high a value as No. 4, the lowest of the iron; while the ratio of difference between the lowest and the highest steel is as 1 to 1·62, and the ratio of difference between the lowest and the highest iron is as 1 to 9·06, showing that the variation between the different samples is 5½ times as much in the iron as in the homogeneous metal.

No doubt this is an extreme case, but it is selected as well adapted to show the full value of homogeneity, which would be perfect in the steel, from its having been worked down to so small a size, but more imperfect than usual in the iron, for reasons which will be given in the last division. As ingot iron is made larger in size, it is less and less uniform, because of internal crystallization, accompanied often with air bubbles. On the other hand, as wrought iron is made larger in size, a greater degree of uniformity can be obtained, as is done in the manufacture of armour plates, by building up from numerous small pieces.

TABLE I.—TESTS OF HOOP IRON AND STEEL.

Hoops 1 in. × 18 w.g.

STEEL.			IRON.		
No.	Breaking Weight.	Elongation.	No.	Breaking Weight.	Elongation.
	lbs.	per cent.		lbs.	per cent.
1	4360	11·50	1	2660	9·00
2	3800	13·25	2	2420	4·50
3	4275	13·00	3	2525	9·25
4	4100	13·50	4	2400	1·25
5	4100	11·00	5	2480	4·00
6	4200	9·50	6	2000	3·00
7	3700	12·00	7	2300	2·50
8	4445	10·50	8	2000	4·00
9	3680	14·25	9	2490	9·25
10	4430	8·75	10	2300	3·50
11	3800	15·00	11	2790	9·75
12	4300	10·50	12	2200	2·00
13	4000	11·75	13	2400	7·50
14	4750	12·25	14	2210	3·00
15	4200	13·00	15	2870	8·00
16	3700	9·50	16	2400	3·25
17	3720	14·75	17	2650	3·50
18	3815	15·00	18	2500	9·75
19	3770	10·25	19	2400	1·50
20	3700	12·50	20	2375	4·50
Average	4042	12·08	Average	2388	5·15

It is not the intention here to deal with plates nor with hammered iron, nor specially with angles or rails, because the experiments now first made public were conducted entirely upon rolled bars. As the manufacture of iron from ingots has undergone great changes, it is obviously unfair to give examples from old sources, and the only available modern data suitable for the comparison are given in Kirkaldy's experiments on Fagersta steel in 1873, Series C3, representing the presence of 0·15 of carbon, from which is extracted Table II. The lowest breaking strain is 23·6 tons per sq. in., and the highest 27·1 tons; the least degree of contraction of area at the point of fracture is 31·4 per cent., and the greatest 72 per cent.; the least degree of extension, over a length of 10 in., is 20·2 per cent., and the greatest 31·1 per cent. Numerous samples of wrought iron of higher breaking strain, and some few with an equal contraction of area and the same degree of ultimate extension, can be found, but probably not of all the three combined, when a sufficient amount of work has been expended upon the steel to make it truly homogeneous, as in the first two or three tests given in the table.

TABLE II.—TESTS OF FAGERSTA STEEL BARS, BY D. KIRKALDY, 1873.

Size of Bars. Length 10″.	Specimens turned to		Ultimate Stress a sq. in. of Original Area.		Contraction of Area at Fracture.	Ultimate Extension.	Appearance of Fracture.
	Diam.	Area.					
inch.	in.	sq. in.	lbs.	tons.	per cent.	per cent.	
½ square	0·357	0·100	60,780	27·1	72·0	22·2	All Silky
1 do.	0·619	0·300	54,560	24·4	69·7	27·8	do.
1½ do.	1·009	0·800	57,960	25·9	56·0	27·3	do.
2 do.	1·382	1·500	57,453	25·6	51·8	28·6	95 per cent. Silky
2½ do.	1·694	2·250	57,345	25·6	31·4	20·2	All Granular
3 do.	1·994	3·000	52,962	23·6	57·8	31·1	All Silky
		Average	56,843	25·4	56·45	26·2	

Puddling may be shortly described as a process for the conversion of cast iron, containing from 3 to 10 per cent. of impurities, into wrought iron, containing, in its first stage as puddled iron, from ½ to 3 per cent. Oxygen is the almost universal agent employed for this purpose, and is obtained principally from oxide of iron in various forms, technically termed fettling. The furnace in which the operation is performed may be considered as consisting of four parts—the grate, the hearth, the flue, and the chimney; but frequently one chimney serves for a number of furnaces. The grate need not be further noticed, except to state that where iron of superior quality, and requiring to be kept very clean, is produced, it is fixed lower than usual, to prevent coal or ash from passing over to the hearth. The hearth of a puddling, or more correctly speaking, boiling furnace, is made of cast-iron plates, which are kept cool by various means to prevent them from melting with the intense heat, and are also covered with oxide of iron or fettling, which is renewed from time to time as required. Usually a heat of 4½ cwt. long weight, or 540 lb., is charged along with some cinder from the hammer or rolls. As soon as the iron begins to melt, it comes in contact with the fettling and cinder in a solid or liquid condition. Chemical action between the two is immediately set up, so that the first melted iron has a greater chance of purification than that melted at a later stage. All round the sides of the hearth the fettling rises some inches above the floor, and as the tools are worked backward and forward and from side to side the melted iron is washed up against it, and therefore the outer portions of the iron are exposed to more fettling than the rest, and begin to thicken first. The puddler scrapes the thick iron into the middle and mixes it thoroughly among the other. The thickening is helped on by the closing of the damper, which is generally done as soon as the iron is properly melted; and when the iron and cinder are well mixed together, the boil generally commences and the damper is raised. As the boil proceeds, the most advanced portions sink to the bottom, and are brought up again and blended with the rest by the puddler's tools. After the melting, mixing, and boiling, comes the dropping as it is called, when the ebullition gradually subsides, till the whole mass lies upon the floor of the hearth in a pasty state. The floor of the hearth is much colder than the upper portion, all the heat being derived from above, so that the action of the fire comes very unequally upon the iron, which is worked up by the puddler, and turned over and broken into small pieces to allow the flame to play upon all parts as uniformly as may be, the damper being lowered at the same time; but as the tools are only very small in proportion to the quantity of iron, and the puddler's strength and activity limited, it is easy to see that at best the working of the iron is only imperfect. Next comes the balling, or making into lumps suitable for the hammer, which is done as expeditiously as possible, putting together the most advanced portions first. But even here, perfection in hitting the right moment with the whole of the iron in the furnace is scarcely attainable; so that there are at every stage causes making against homogeneity, which it requires all the best efforts of the workmen to keep in check. These causes are increased sometimes by the furnace working with the flue slanting upwards directly into a firebrick chimney, the brickwork of which gradually melts away, and theoretically should come into the furnace, heat by heat, in which case little harm would be done; but in practice the puddler keeps it back by the fettling, and now and again it runs into the furnace all at once, and in many cases spoils a heat. Frequently the effect is to produce fibre, by the diffusion of a thick cinder throughout the mass, preventing the formation of crystals, but the iron is generally weak and red-short. When a short flue is carried from the furnace to a boiler, the quantity of melted brick is scarcely worth notice.

Pure iron appears to be soft and ductile, strength is added to it by the presence of carbon, and speaking generally it may be said that iron is good so far as it is free from all other elements, excepting perhaps manganese. But carbon, though a most valuable accompaniment of pure iron, seems to be highly injurious in connection with phosphorus and silicon in quantity. These elements, which along with other foreign matters impart fluidity to iron, first of all appear to reduce the amount of carbon in the pig; such iron comes readily to the boil, and the liquid condition being maintained by the presence of the other impurities, the boil may be prolonged to a later stage of decarbonization than can be done with better iron: hence it is possible to reduce the carbon to a mere trace by well and careful working, and to make the iron soft, fibrous, weldable, and apparently very good, though it has never yet been proved equal in all respects to that produced from a higher quality of pig. The ordinary expression applied to it by consumers of first-class iron is that it wants "body," which appears to mean neither more nor less than that it lacks strength, is not sufficiently pure, and is short of carbon. But when all other elements are reduced to a very slight percentage, the carbon is pretty certain to be unusually high, and the iron when broken suddenly by a smart blow upon the anvil after cutting through the skin is almost invariably crystalline or granular, though really capable of bearing a high tensile strain, contracting very much at the point of fracture, and elongating considerably; when not broken suddenly, the appearance is fibrous, and the fracture under tensile strain is generally all fibrous. Such iron must be good, despite its crystals, and as it improves with working, it is better in the manufactured article than in the bar; while iron made fibrous by a mixture of strong cinder, and working comparatively cold in the finishing heat to prevent this cinder escaping, is never equal in point of strength and ductility to the other, and is very apt, with the least degree of overheating by the smith, to become extremely brittle.

Kirk observed these phenomena forcibly in the course of some experiments undertaken with a view to ascertain the properties of several kinds of iron, chiefly from hæmatite ores. The heats given were all of full weight, no extra time was spent over them, no extra fettling used, and no additional heat was employed to purify the iron to a greater extent than was likely to be done in actual every-day work. The puddled blooms were rolled into bars without reheating, and finished at a second heat, except four of the samples, the results of which are represented in Tables V. and VI.

Table III. gives the tests of four bars of Marron iron of various sizes and shapes, from four different puddled bars of one heat. The ultimate stress ranges from 24 to 27·3 tons a sq. in.; the contraction of area from 40 to 52·4 per cent.; the extension, taken over a length of 10 in., from 22·1 in the smallest size to 24·2 per cent. in the largest. There was considerable difference between the properties of the first and the last of the four, and an analysis of each was taken, the first and second of Table VI., the last being highest in carbon, and probably, from the greater total percentage of the various elements, lowest in cinder.

TABLE III.—TESTS OF MARRON IRON BARS, BY D. KIRKALDY, 3RD JULY, 1876.

Size of Bars. Length 10″.	Original Area.	Ultimate Stress a sq. in. of Original Area.		Contraction of Area at Fracture.	Stress a sq. in. of Fractured Area.	Ultimate Extension.	Appearance of Fracture.
inch.	sq. in.	lbs.	tons.	per cent.	lbs.	per cent.	
$\frac{9}{16}$ diam.	0·255	61,282	27·3	40·3	102,809	22·1	Fibrous
$\frac{9}{16}$ square	0·331	55,791	24·8	42·9	97,709	23·0	do.
$\frac{3}{4}$ do.	0·570	54,894	24·5	40·0	91,491	24·2	do.
$\frac{1}{2}$ do.	0·265	53,603	24·0	52·4	112,738	22·9	do.

In Table IV. the first four samples represent two puddled bars of the same heat, M indicating middle of bar, E end of bar. One piece was taken from the end and the other from the middle of each finished bar. The samples range from 24·1 to 26·9 tons a sq. in. ultimate stress, from 32·8 to 46·7 per cent. contraction, and from 22·7 to 26·2 per cent. extension over 10 in. length. The first of this list presented the unusual feature of being worst welded in the middle of the bar, caused by the pile being charged after the rest, and drawn before the heat had permeated throughout. When fractured, it exhibited the five pieces of the pile very distinctly, though the end of the bar was well welded. An imperfect weld reduces a bar to a series of flat plates, and it is well known that plates neither contract at the broken part nor elongate so much as rounds and squares.

TABLE IV.—TESTS OF MARRON IRON BARS, BY D. KIRKALDY, 24TH JULY, 1876.

Bars 10 in. length.

Diameter of Bars.		Original Area.	Ultimate Stress a sq. in. of Original Area.			Contraction of Area at Fracture.		Stress a sq. in. of Fractured Area.	Ultimate Extension.		Appearance of Fracture.
inch.		sq. in.	lbs.	lbs.	tons.	per cent.		lbs.	per cent.		
$1\frac{1}{8}$ diam.	M	0·968	60,351	59,584	26·6	32·8	37·1	94,786	22·7	23·3	Fibrous.
$1\frac{1}{8}$,,	E	,,	58,817			41·4			24·0		,,
1 ,,	E	0·785	54,203	54,114	24·1	46·7	46·7	101,626	26·1	26·1	,,
1 ,,	M	,,	54,025			46·7			26·2		,,
$1\frac{1}{8}$,,	M	0·968	52,747	52,564	23·5	44·1	44·7	95,191	26·5	25·8	,,
$1\frac{1}{8}$,,	E	,,	52,381			45·4			25·2		,,

Table V. and the last five items of Table VI. give the results of the most important trial of all, because they represent the whole of a puddled heat both in tests and analyses. The sizes of iron are all the same, which is better for comparison with each other. The breaking strain is from 23

TABLE V.—TESTS OF MARRON IRON BARS, BY D. KIRKALDY, 31ST AUGUST, 1876.

Bars 10 in. length.

Description of Iron.		Original Area.	Ultimate Stress a sq. in. of Original Area.			Contraction of Area at Fracture.		Stress a sq. in. of Fractured Area.	Ultimate Extension.		Appearance of Fracture.
		sq. in.	lbs.	lbs.	tons.	per cent.		lbs.	per cent.		
W.S.	M	0·442	56,515	55,803	24·9	42·3	40·9	94,501	24·1	23·3	Fibrous
,,	M	,,	56,470			40·2			22·6		,,
,,	E	,,	54,423			40·2			23·1		,,
W.T.W.	M	,,	55,791	55,689	24·8	46·1	41·3	94,916	24·1	23·0	,,
,,	M	,,	55,723			46·1			23·8		,,
,,	E	,,	55,554			31·6			21·1		,,
W.5	M	,,	55,780	55,048	24·6	42·3	41·6	94,308	23·9	22·1	do., 5 p. c. crystalline
,,	E	,,	55,361			40·2			20·1		Fibrous
,,	M	,,	54,004			42·3			22·3		,,
W.R.5	M	,,	55,226	54,747	24·5	46·1	40·8	92,595	24·8	23·2	,,
,,	E	,,	55,181			38·2			22·6		do., peculiar
,,	M	,,	53,834			38·2			22·3		,,
W.R.3	M	,,	52,138	51,728	23·1	50·0	50·0	103,457	25·9	25·8	Fibrous
,,	M	,,	51,961			50·0			26·0		,,
,,	E	,,	51,085			50·0			25·5		,,

TABLE VI.—ANALYSIS OF MARRON BAR IRON, G. F. DOWNAR.

Size of Bars.	Description.	Iron.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Total.
inch.		per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
$\frac{9}{16}$ diam.	..	99·533	0·165	0·067	0·011	0·075	Trace	99·851
$\frac{1}{2}$ square	..	99·530	0·190	0·074	0·010	0·091	„	99·895
1 diam.	..	99·533	0·170	0·047	0·011	0·045	„	99·806
$\frac{3}{4}$ „	W.S.	99·498	0·120	0·116	0·015	0·091	„	99·840
$\frac{3}{4}$ „	W.T.W.	99·326	0·150	0·128	0·012	0·132	„	99·748
$\frac{3}{4}$ „	W.5	99·500	0·115	0·149	0·011	0·161	„	99·936
$\frac{3}{4}$ „	W.R.5	99·498	0·090	0·163	0·022	0·182	„	99·955
$\frac{3}{4}$ „	W.R.3	99·704	0·180	0·019	0·014	0·074	„	99·991

to 25 tons a sq. in.; the contraction from 31·6 to 50 per cent.; the extension, over 10 in. length, from 20·1 to 26 per cent. An effort was made in this heat to get the carbon lower than before, and it gave an average of carbon 0·131 per cent., against an average of 0·175 per cent. in Tables III. and IV.; but the sum of the phosphorus and silicon had risen from 0·133 to 0·243 per cent., and it will be seen that in Table VI. itself as the carbon falls the phosphorus and silicon increase. Thus—

		Carbon.	Phosphorus and Silicon.
W.R.3	contained	0·180 per cent.	0·093 per cent.
W.T.W.	„	0·150 „	0·260 „
W.5	„	0·115 „	0·310 „
W.R.5	„	0·090 „	0·345 „

W.S. is here omitted, because it was treated in an entirely different manner from the rest, by which the cinder was better extruded, and it is not therefore eligible for comparison, because some of the phosphorus and silicon appearing in the analysis of iron properly belongs to the cinder remaining in it.

There is a probability that these oscillations of carbon on the one hand and phosphorus and silicon on the other are not accidental, but are really cause and effect. A considerable amount of carbon often remains in the puddled iron after it has reached a spongy condition, and the cavities of it are filled with cinder, which generally contains a good deal of phosphoric acid and silica. It is likely that some of the oxygen for the removal of the carbon is obtained from this cinder, and that it sets free iron, phosphorus, and silicon, which are added to the puddled ball. Colouring is lent to this supposition by the behaviour of puddled iron at the hammer, by the effect of a puddled heat waiting in the furnace after it is made into balls, and by the composition of puddled-ball cinder. Frequently a slight flame is observed from a puddled ball, and when the hammer drops upon it, and the cinder is thereby brought into closer contact with the iron, it is immediately covered with the flames of carbonic oxide. When the puddled balls remain too long in the furnace, the quality of the iron is greatly impaired; though the causes of this do not appear to have been investigated, it is a well-known fact. It may be that occluded gases have something to do with it, as well as the cause just referred to. Cinder expelled from puddled balls is invariably poorer in iron and richer in silicon and phosphorus than the cinder left in the furnace at the time the balls are withdrawn.

Without attempting to trace any very close connection between the mechanical properties and the chemical composition of the different samples given in Tables III. to VI., which were of iron chiefly made from Moss Bay hæmatite, attention may be very properly drawn to one fact which comes out with remarkable clearness. It has frequently been contended in making tests that the true value of any iron is shown by the amount of stress at the fractured area, and there can be no doubt that this shows its real strength. It will be found throughout that as the carbon increases so does the stress a sq. in. at the fractured area. Thus—

Carbon.	Stress at Fractured Area.	Original Area.
0·090 per cent.	92,595 lb. a sq. in.	0·442 sq. in.
0·115 „	94,308 „	0·442 „
0·120 „	94,501 „	0·442 „
0·150 „	94,916 „	0·442 „
0·165 „	102,809 „	0·255 „
0·170 „	101,626 „	0·785 „
0·180 „	103,457 „	0·442 „
0·190 „	112,738 „	0·265 „

The apparent exception in the case of 0·170 per cent. is due to the area being three times as great as in 0·165, and therefore having a much less amount of work put upon it, and the immense increase of strength from 0·180 to 0·190 is mainly accounted for by the extra work put upon the latter.

It has been stated previously that a mixture of iron and cinder is not compatible with homogeneity. The great capacity for heat possessed by iron of unusual purity gives better facilities for expelling the cinder, besides which it does not stick in such iron so pertinaciously as in that of lower quality.

Of the analyses presented in Table VII., which are of ordinary qualities of bar iron, the first, second, and fourth represent a description of iron very much in favour for years past, soft in its hot as well as in its cold state, easy to weld and fibrous. The third was similar, but not entirely fibrous; it has been added just to show the influence of carbon along with silicon and phosphorus in quantity. It will be seen that all the four are much lower in metallic iron than the previous samples, and that the total percentages are also lower. Ordinary chemical analyses do not distinguish between iron and its oxide—it is all given as iron, whereas there may be $\frac{1}{2}$ per cent. or more existing in combination with oxygen; and the weight of oxygen not being given, this causes the total percentage to fall short in the more impure article.

TABLE VII.—ANALYSIS OF BAR IRON.

(*Ordinary qualities.*)

Size of Bars.	Description.	Iron.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Total.
inch.		per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
$\frac{3}{4}$ diam.*	K.B.W. ♛	98·625	Trace	0·258	0·052	0·321	Trace	99·256
$\frac{3}{4}$ " *	"	98·983	"	0·174	0·038	0·289	"	99·484
$\frac{5}{8}$ " *	"	99·064	0·075	0·224	0·035	0·310	"	99·708
$1\frac{1}{4} \times \frac{1}{2}$ †	K.B.W. ♛ Best	99·115	Trace	0·170	0·028	0·200	0·140	99·653

From what has already been advanced, the true means of ensuring such a degree of homogeneity as is possible by puddling appear to lie in the production of iron as pure as may be with its attendant carbon; and it is believed that if iron were puddled with a view to the best possible quality and the greatest degree of homogeneity without any regard to the presence or absence of fibre, the carbon would run still higher than in Table VI., and that the iron would be more valuable in every way if its properties were appreciated and its peculiarities understood If it be true, as it appears to be from the foregoing observations, that the most valuable iron is that which is purest, along with sufficient carbon to impart strength, it is obviously bad policy to replace carbon by phosphorus and silicon, even though that replacement should be accompanied by the substitution of fibre in a nicked and suddenly broken sample for fine crystal or grain.

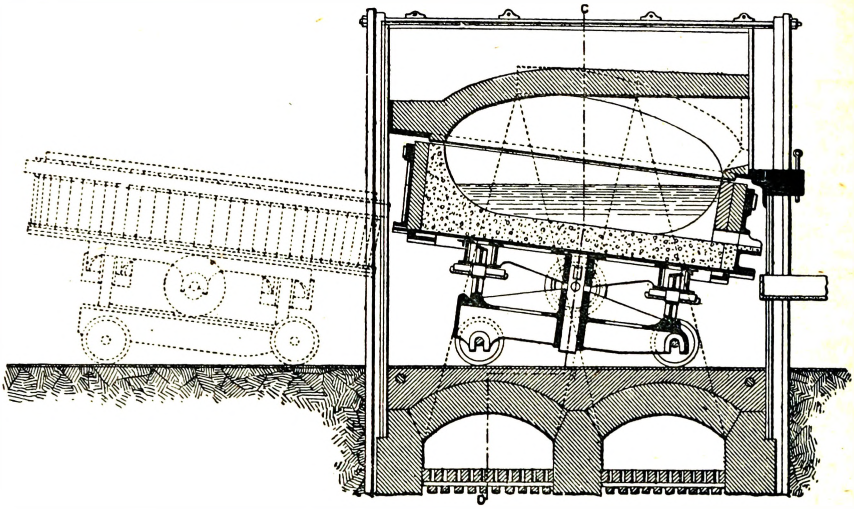
Mechanical rabbles are now worked only to double furnaces, having two doors opposite each other, a rabble being placed to work through the stopper-hole of each; but these furnaces, as usually constructed, are objectionable in several respects. In the single furnace, the roof is made highest over the door, to counteract the effect of the air drawing in at the working hole and at the crevices about the door and door-frame, which contrivance brings the flame tolerably well to the front; but the double furnaces are highest in the middle, and the flame is not therefore so well equalized. The depth of the hearth below the fore-plate upon which the door rests, and which serves as a support for the puddler's tools and as a fulcrum whenever leverage is required, is generally greater than in a hand furnace, in order to prevent iron and cinder being raked out by the motion of the rabbles; this causes the workman extra labour when he is obliged to work without the machine, which is a longer period than the machining, so that there is a per-contra to the saving of labour by the machine. The double furnaces, having no backwalls, have of course much less brickwork and fettling in proportion to the charge of iron than single furnaces, the results of which are saving of fuel and of fettling; but the furnaces, having a smaller reservoir of heat in the absence of the backwalls, work more slowly and do not regain their full temperature so soon after having been cooled down for any purpose, such as cleaning the grate or lowering the damper to bring on the boil. This is a great drawback in working iron that requires a good deal of dampering and the heat restoring rapidly after the damper is raised. The saving of fettling when there are few of such furnaces, in what may be termed the experimental stage, among a number of the ordinary kind, is often made up by a free use of mill scale, and by the oxidizing of a larger quantity of scrap to keep the bottom good. When not so made up, a better mixture of iron must be resorted to, or more waste of iron will be incurred, or else worse iron will be made, that is, of course, always supposing that the mixture of iron and the quantity and kind of fettling are properly adapted and adjusted to each other in the single furnaces. Double furnaces sometimes work hotter on one side than on the other, which is vexatious, for the damper occasionally wants lowering to suit the condition of the iron on one side, and keeping up to suit it on the other side, but as the same damper generally acts for both this cannot be done. It also happens now and then that the wind blows in strongly at one stopper-hole and drives the flame out of the other, to the annoyance and inconvenience of the workmen. There is not apparently anything about the system of mechanical rabbling generally to give grounds for expecting a greater degree of homogeneity in iron made by this than by the ordinary methods, though double furnaces unquestionably save fuel.

The Casson-Dormoy furnace, with Casson's gas-producer, has a grate much wider than the hearth, which is circular, and the furnace appears to keep pretty well filled with flame.

The Maudslay or Pernot furnace, the floor of which is upon an inclined plane, and which rotates in this position, is an advance upon the foregoing, because it exposes the iron alternately to the action of the cinder when it comes to the lowest part and then to the flame of the furnace without the covering of cinder; but there is still the disadvantage of the colder bottom, and of turning over and balling by manual labour.

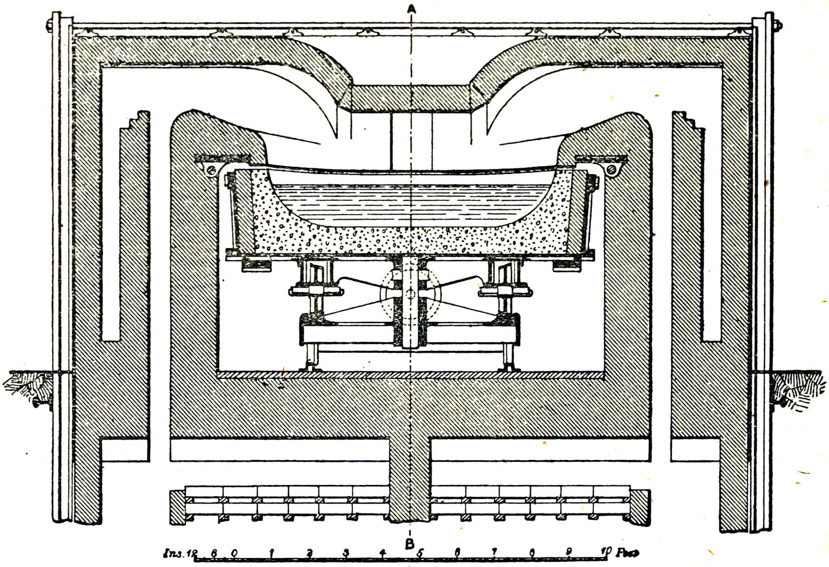
The Pernot furnace, Figs. 1577, 1578, consists of a fixed fireplace, roof, and flue, together with a movable furnace bed and its support. The fireplace is of the ordinary form, and is provided with a charging door on each side of the furnace, with four small orifices, closed by cast-iron doors, serving for the introduction of an iron rod for the purpose of stirring the fire; the ash-pit is closed by doors of sheet iron, and a current of air from a fan is admitted beneath the grate by a valve. When the grate is sufficiently furnished with coal, it acts to a considerable extent like a gas generator, and fills the furnace with reducing flame. The dome is circular, the brickwork resting upon an iron ring cast in segments; this ring is inclined downwards towards the front of the furnace, and is on a level with the fire-bridge, which is also inclined. Both doors are in the front of the furnace or in the portion corresponding with the lowest part of the revolving bed, the door next to the flue being considerably larger than that adjacent to the fire-bridge. The flue is placed opposite to the fire-ridge, upon the same level, and having the same inclination. It leads either into a chimney or into a regenerative chamber. The whole of the fixed structure is strongly braced, and beneath it is a rectangular cavity into which the movable bed with its supporting carriage may be introduced. The revolving bed consists of a circular trough, of which the bottom is a plate of sheet iron, the sides being formed of an iron ring cast in segments, and fastened to the bottom by bolts so placed as to be accessible without disturbing the lining or fettling. The upper portion of the cast-iron ring forming the sides of the bed is strengthened by a second, also cast in segments and bolted together.

1577.



Beneath the iron plate forming the bottom of the bed is fixed the mechanism which permits of its rotation on an inclined axis. This consists of a slightly conical toothed wheel, cast in segments, and fixed by bolts to the periphery of the bed on its under side. Within this wheel a casting is fixed in the form of a cross, each arm of which bears a conical wheel destined to run upon a conical road on the carriage. The centre of the cross is fitted with a bearing which works upon a shaft inclined at an angle of about 6° or 7° from the vertical. The carriage runs on a pair of rails laid in the cavity beneath the furnace, and can be readily withdrawn when repairs are necessary.

1578.



The bed is moved by a toothed pinion attached to the carriage and gearing with the conical toothed wheel on the under side of the bed. The pinion, by means of a coupling similar to that used for joining the rolls of a train, obtains its motion from an engine of from 2 to 3 H.P. This coupling serves for disconnecting the shafts previous to the withdrawal of the rotating bed. The latter is formed of small fragments of "Mokta," together with hammer-scale and slags from shingling, the surface of which fuses, and forms a glaze that cements the mass. The interior of the furnace is kept full of reducing gases, and the current of air is so regulated that flame issues from the joint between the movable bottom and the fixed part of the apparatus, which it is found impossible to keep entirely tight. The furnace bottom is kept cool by a continuous jet of water playing against it.

The average rate of rotation, whether for the manufacture of iron or of steel, is about three revolutions a minute.

The method of working this furnace differs considerably, according to the description of pig iron to be converted. For ordinary cast iron the following system is observed;—As soon as one charge has been withdrawn and shingled and the grate cleared, the temperature falls considerably, and the slag remaining on the hearth becomes pasty. The workman sets the hearth in motion, and with a suitable tool spreads the slag against the sides and towards the centre of the bed in a symmetrical manner; the fire is now urged, and as soon as the desired heat has been attained, the requisite quantity of hammer-scale and slag is added, and finally the cast iron. When the fusion is complete, the charge has a tendency to rise, owing to the rotation of the hearth, and is constantly rolling back into the lowest portion of the bed. Since, however, the rate of rotation never exceeds three revolutions a minute, this movement is insufficient for the proper stirring of the charge. The puddler therefore assists the stirring by placing his tool against the side of the working door, and allowing the end to rest on the hearth. In this way every part of the charge is brought into contact with the stirrer, and the laborious work of ordinary puddling is dispensed with.

When the iron commences to come to nature, the stirrer is withdrawn, and a tool with a flattened end is introduced and held against the side of the door, with the flat portion resting in the molten charge. This serves to prevent the collection of the minute particles of iron on the bottom of the furnace as soon as formed. When the ferruginous mass has attained a certain consistency it no longer falls back into the lower part of the hearth, but is carried around with it, and is thus at each revolution plunged into a bath of molten slag. As soon as the ball is formed the furnace is stopped, and the large mass is divided into a number of smaller ones, which are taken one by one to the shingling machine. The labour required for a furnace of this description consists of two puddlers, two assistants, a fireman, and a boy to look after the engine. The only labour of an excessively fatiguing description is that necessary for the separation of balls from the larger mass.

The average production of rough iron a day of twelve hours is 7691 lb.; the labour necessary for the manufacture of 1 ton of iron being: puddler, 0·57 day, and fireman and engineer, 0·28 day. The loss of iron is small, and the consumption of coal amounts to 2332 lb. a ton of iron produced. The iron is of better quality than that produced in the ordinary furnace, the production of rough iron in which is given as;—Average make in twelve hours, 2370 lb.; labour a ton, 0·93 day puddler; loss of iron, 7 per cent., and consumption of fuel 3329 lb. a ton of iron made.

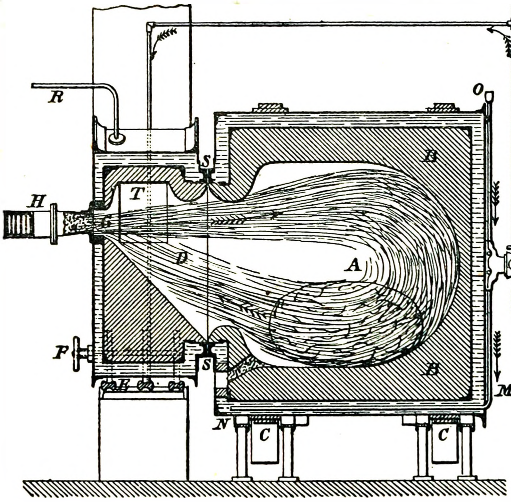
The form of furnace revolving on a horizontal axis appears to give the greatest promise for the future, if those who employ it will only study chemical action and work according to it, instead of trying to overcome their difficulties by merely mechanical contrivances. When iron is charged cold into these furnaces the evils pointed out in the ordinary furnace are intensified, because a greater quantity of melted fettling is present, but the iron ought always to be charged liquid. The working of the iron while it remains liquid is far more thorough than in the best of the other systems noticed, but when the iron becomes pasty there is no means of opening it out as is done by a good puddler, and consequently the advantage is to some extent lost in the latter portions of the heat.

Danks's furnace does not give much promise of homogeneity, inasmuch as from various causes, including imperfect working of the puddled ball, there has been generally a large quantity of very thick cinder present, difficult to expel.

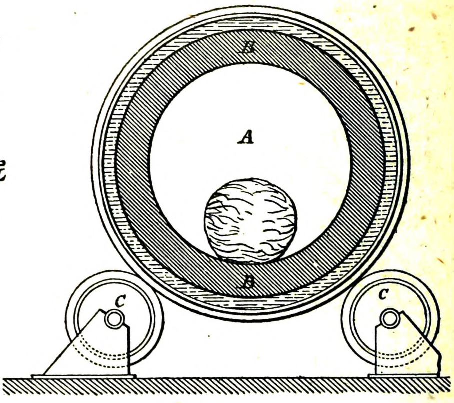
In Crampton's puddling furnace, Figs. 1579 to 1582, A is a revolving chamber which is made to rotate on a horizontal axis; the speed can be adjusted to any velocity up to 10 revolutions a minute; B B is the refractory lining, and C C the wheels on which the furnace revolves. D is the movable flue piece lined with refractory material, capable of being removed when access to the furnace is required; the flue piece rests upon three wheels E, which run on iron rails and have screws F on the axles of the wheels for keeping D against the furnace. G is an opening through which the air and fuel are injected. H is the pipe through which regulated streams of air flow, and which conveys the fuel from the coal reservoir to the furnace through the nozzle I. A plan of this is shown enlarged in Fig. 1581; and at K are several partitions in the bend of the injection pipe for the purpose of preventing the fuel and air separating on passing the bend. L is a double-way cock for the admission and exit of the water at the double casing of the furnace. The water enters at L, passes into the pipe M, and is delivered at the end N into the casing, circulating through the whole casing and making its exit at the end of the pipe O, passing thence to the cock L, and leaving it by the pipe P. The water is then conducted by P to the flue piece entering through a flexible pipe at the lowest point and leaving at the highest point at R. S S are the wearing joints of the furnace and flue piece directly in contact with the water casing. T is the opening for the exit of the products of combustion into the chimney, where they may be utilized in producing steam or heating the air, or both.

The coal, which is ground and sifted previously, is brought into a tank U, Fig. 1582, by a creeper. In order that the powdered coal may not clog, stirrers V are used, which serve also to bring the coal from the tank to the feed rollers W W. The opening from the tank can be made larger or smaller as required by a sliding door X. The distance between the rollers can be adjusted and the feed regulated with accuracy by a lever and screw Y; two scrapers clear the rollers. The coal falls through a shoot Z to the air pipe H, into which it is induced by the current of air traversing it from a blast reservoir.

1579.

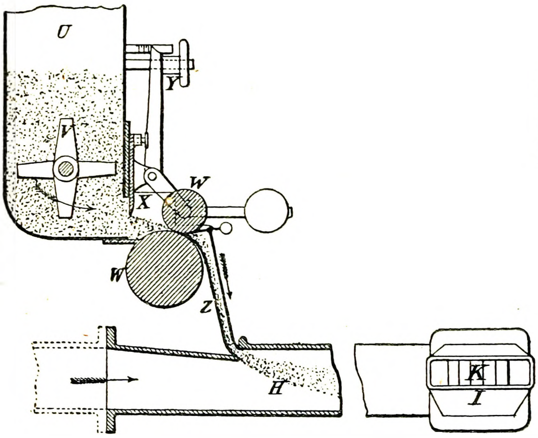


1580.

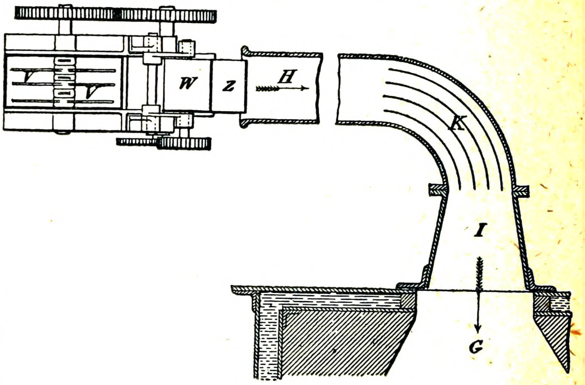


The Crampton furnace, assisted by the equable character of its flame, and the means afforded of keeping it in perfect command, would seem to give the greatest promise of any in the direction of homogeneity. Though the amount of fettling used is very great, the purification of the iron is most extraordinary, and such purification has been shown to be one of the conditions favourable to homogeneity. Further, when the coal is suitable the cinder is thinned by the silica from the ash, and the bulk of it can be easily driven out of the iron.

1581.



1582.

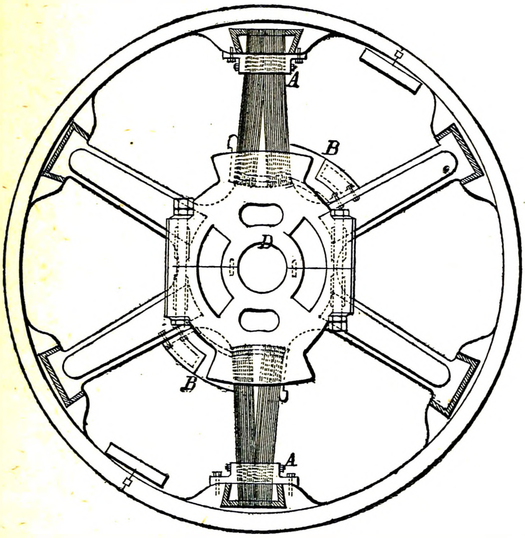


With respect to the subsequent operations, the puddle-bar system is really the outcome of an effort to obtain uniformity, the causes making against which in puddling have already been dealt with. Probably it was thought at first that rolling the puddled iron into flat bars, cutting up, and piling would divide the irregularities by the number of pieces in the pile, as well as improve the iron by putting more work upon it. But it does more than this: any iron not properly worked, when rolled off from the puddled bloom without reheating, tears into holes of various sizes, from the smallest speck upwards, by the action of the rolls; and when the pile is subjected to the heat of the furnace, these holes allow the raw places to receive a greater share of the heat, and they act as receptacles for cinder melting off the iron, both of which tend to purify it in a high degree, for it must be remembered that this cinder is much superior to that in the puddling furnaces. Another advantage is that any badly puddled iron shows crystal in cutting cold at the shears into the lengths required for the pile, and can be thrown out. The very great irregularities in the samples of hoop iron given in Table I. may be largely accounted for by the fact that they were rolled from billets, being too small a size to make out of piles.

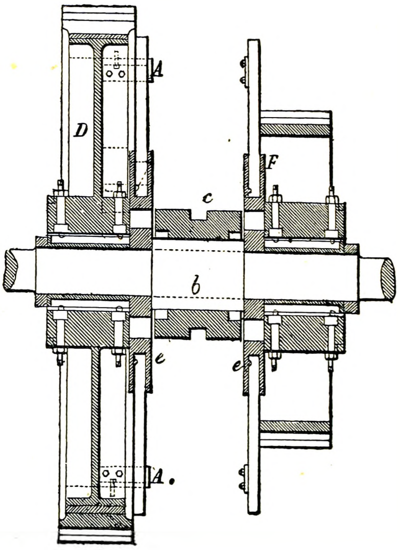
Table V. exhibits five different methods of working. The first upon the list, W.S., was worked out of the solid, and though it is the highest in breaking strain, and the three samples were all from the same puddled bar, it yet shows the greatest amount of difference in this respect of any of the samples. W.T.W. was rolled off into puddled bars, piled and rolled again into flat bars, which were again piled and finished at a third heat. It will be seen that it varies least of any in ultimate strength, from the different parts being so well blended. W.5 was rolled from five pieces of puddled bar without reheating, just as in the ordinary way, and except in the item of elongation it gives superior results to W.R.5, in which the only difference is that the puddled bloom was reheated before rolling. W.R.3 was well hammered twice and piled only three high, so as to have fewer welds. Taking the contraction of area, which is 50 per cent., and the extension 25·8 per cent. over 10 in. length, along with the breaking strain of 23·1 tons a sq. in. of original area, it is the best given in the table; but as the analysis is also superior to any of the rest, it would probably be misleading to attribute its excellence to the method of working.

In the reversing rolling mills so largely employed in ironworks, serious evils arise from the shock occasioned by the clutches used. To remedy this, Ramsbottom introduced a system of reversing by means of a pair of engines without a flywheel, whilst many devices, such as those shown at pp. 2113 to 2117 of this Dictionary, are in favour. All of these have, however, greatly fallen short of affording the amount of gradual engaging action necessary to prevent shock, whilst the application of Ramsbottom's system involves a complete alteration of engines and gearing.

1583.



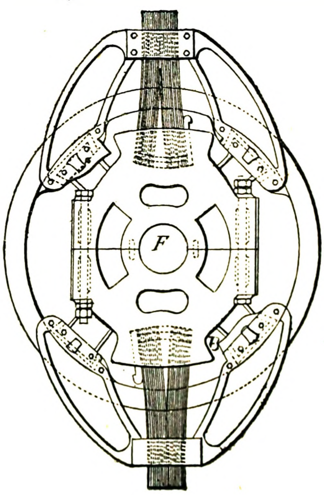
1584.



The reversing gear of J. Head of Middlesborough, Figs. 1583 to 1590, is specially devised for the conversion of such existing reversing gears into thoroughly efficient ones, without any fundamental alteration, and without rendering useless any of the existing parts. The plan consists of the introduction of a loose face between each loose wheel and the clutch. These loose faces are bored out to the same diameter, and are carried upon the same portion of the loose axle as the spur wheels with which they are in contact. Cast in them are recesses B corresponding to, and engaging with, the claws of the sliding clutch, instead of those claws being made to engage with recesses in, or claws upon, the inner faces of the loose spur wheels themselves. Each loose face is made in two halves, firmly bolted together, so that one or both halves may readily be removed and replaced whenever necessary. Cast in the back of each half of each loose face is a recess, into which is secured an arm composed of bars of spring steel, and somewhat resembling one-half of an ordinary bearing spring, such as surmounts the axle-box of a locomotive. The extremity of the spring arm is held in a socket A attached to the inside face of the loose spur wheel with which it is in contact.

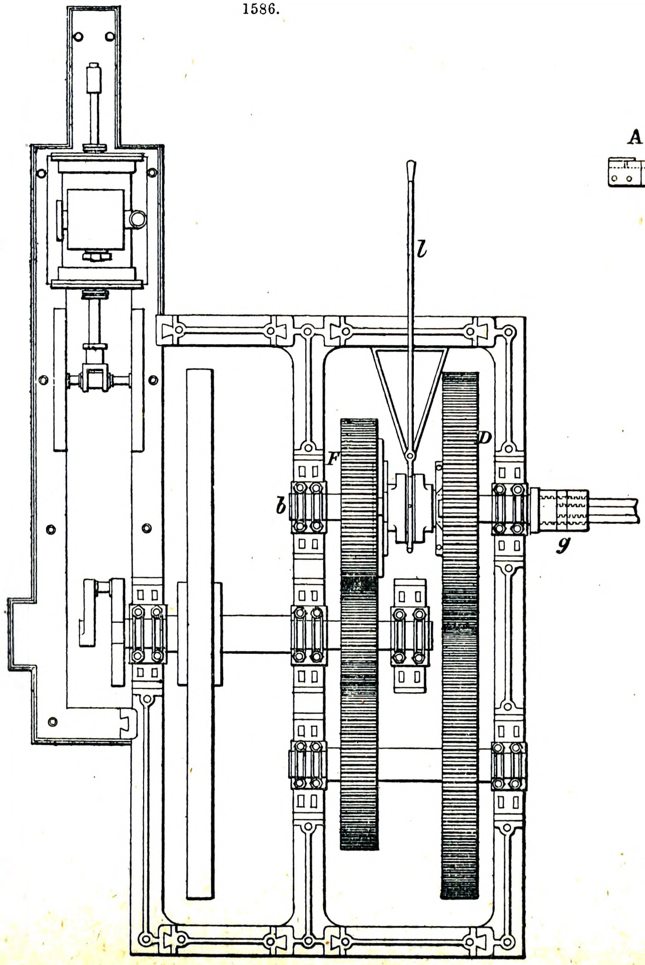
In Figs. 1583 to 1590, Fig. 1586 is a plan of the mill, Fig. 1590 section of the wheel, Fig. 1583 and Fig. 1588 a section of Fig. 1585. D is a 12 ft. 2 in. loose wheel, F a 7 ft. 6 in. loose wheel, *e e* the loose faces, *b* the loose axle, *c* sliding clutch, *g* fast and loose crabs, *p* pinions, *r* roughing rolls, *r'* finishing rolls, *l* the reversing lever.

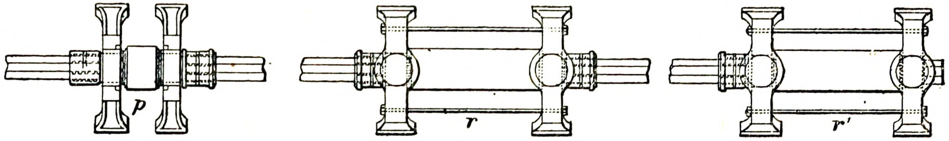
1585.



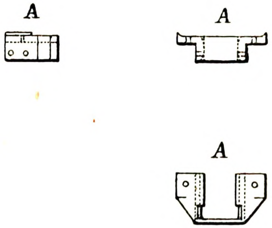
In the act of reversing, the clutch is ordinarily thrown to one side or to the other, in order to communicate to the shaft, upon which it slides, the motion of either of the loose spur wheels with which it engages, and which, by means of the wheel-work behind them, are permanently rotating at constant speeds in opposite directions. Precisely the same takes place with Head's reversing gear, except that the loose shaft acquires motion, not direct from claws, solid with the rotating spur wheel, but only as the force in the rim thereof can be transmitted to it, through the two spring

1586.

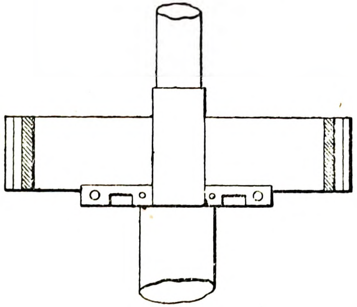


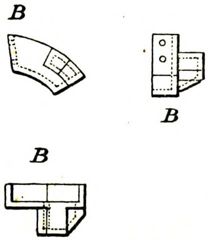


1587.

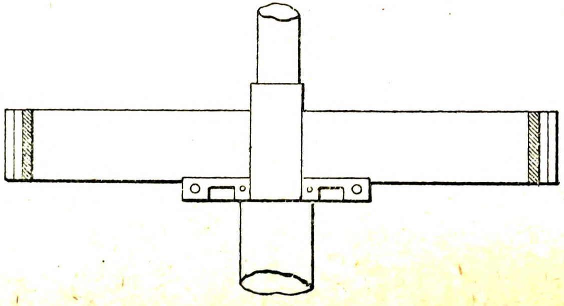


1588.





1589.



1590.

arms attached to the loose face. These spring arms yield to a certain extent, just as the spring drag-hook of a locomotive does, when it suddenly endeavours to set a heavy train in motion.

In ordinary reversing gear, the momentum of the loose spur wheels, the other wheels and shafts connected with them, and the heavy fly-wheel upon one of those shafts, all rotating at a considerable velocity, cannot suddenly be checked without injury. On the other hand, the loose shaft with the clutch upon it, and the rolls, spindles, and boxes, in connection with it, cannot be set into rapid motion from a state of rest, and this operation repeated several hundreds of times a day, without eventual destruction. By the introduction of the spring arms, Figs. 1583 and 1585, the only dead weight which is made suddenly to change its state of motion is the loose face, whose weight is comparatively small, and which, being made of cast steel or wrought iron, will wear for a considerable length of time.

The weights which are suddenly set in motion from a state of rest, in this and in an ordinary reversing gear, adapted in both cases to a 22-in. plate mill, are—

In Head's reversing gear—

	tons.	cwt.	qrs.	lb.
One loose face weighing	1	10	0	0

In an ordinary reversing gear—

	tons.	cwt.	qrs.	lb.
Loose axle	3	0	0	0
Sliding clutch	1	11	3	0
Fast and loose crabs attached to the end of the loose axles	1	12	2	0
Total	6	4	1	0

To be set in motion at each reversing there are, besides the 6 tons—

	tons.	cwt.	qrs.	lb.
4 spindles	1	7	0	0
7 boxes	3	1	1	0
2 pinions	3	14	0	18
3 rolls	13	4	1	0
Add as above	6	4	1	0
Total	27	10	2	18

without taking into account the upper chilled roll which is usually left uncoupled. Although the 6 tons 4 cwt. 1 qr. in contact with the loose axle, is set into motion suddenly at each reversing, the remainder, 21 tons, acquires motion only by a succession of blows, owing to the slackness of fit between the coupling boxes and the spindles, and the ends of the rolls.

In setting in motion so considerable a weight, it is obviously better to do so by a series of blows than by a single one; still, all shocks are mischievous. By introducing springs between the fly-wheel and the point of ultimate resistance, the minor shocks are mitigated, as well as the initial one produced by throwing in the clutch. The proportion of a revolution which the spring will yield, is about one-fortieth. Head regards this as ample. He ascertained by taking numerous diagrams that the maximum force exerted in rolling an ordinary plate, amounted to a load of 17 tons upon the engine piston moving at the rate of 272 feet a minute. This will be found equivalent to $7\frac{1}{2}$ tons exerted at the extremities of the two spring arms, or $3\frac{3}{4}$ tons upon each. The spring arms at their base are composed of forty-four plates $3\frac{1}{2}$ in. wide and $\frac{5}{16}$ in. thick. The total thickness of the layers of plates amounts to 14 in., and according to the usual formula derived from experience with locomotive springs, namely;—

$$L = \frac{BT^2N}{11{\cdot}3\,S},$$

where

L = safe load in tons,
B = breadth of plates in inches,
T = thickness of plates in sixteenths of an inch,
S = span of spring in inches,

and

N = the number of plates at the thickest part of the spring,

they are as safe as those springs ordinarily are, even when subjected to the maximum strain which can ever come upon them in rolling. Should, however, the spring arms have failed to impart their motion to the sliding clutch and loose axle, after having yielded as much as they are capable of, as might be the case if a stoppage occurred at the rolls, then certain projections upon them come in contact with safety claws, secured, as in Fig. 1583, to the arms of the loose wheels. This plan prevents any danger which might otherwise arise from breakage of the spring arms, or from these being drawn out of their sockets at their extremities. If the loose faces come in contact with the safety claws, as described, they become solidly united to the loose wheels, and in such cases the reversing gear becomes similar to those in common use. In the case of the smaller loose wheel, it is necessary to carry out brackets beyond the diameter of the wheel to engage the ends of the spring arms in contact with it, in order to obtain a sufficient length for elasticity, and in order to make the same duplicates applicable to either wheel. The spring arms with brackets might, in this case, be sometimes found to interfere with the outer carriage of the fly-wheel shaft supporting the middle pinion. If it should be inadmissible to work that pinion, the carriage may be moved a little further from the pinion, and the spring arms allowed to work in the space between, close up to the naked fly-wheel shaft.

In various parts of the world iron ores are to be found which are very rich, but in so pulverized a state that they are difficult to deal with in the blast furnace; if these ores can be reduced to a useful metal by a chemical process they will effect an important addition to the quantity of iron available for industrial uses. There are several methods of effecting this by producing a kind of sponge, and although this process will not affect the production by means of the blast furnace, it is undoubtedly valuable where the fuel is of a friable and the ore of a refractory nature. If it is attempted to reduce a very refractory ore with such a fuel in the blast furnace the result is almost certain to be a failure, whereas by a little extra trouble and remelting of the sponge a yield can be obtained almost as good as by the ordinary smelting process. With regard to the objection that iron sponge takes up sulphur, no doubt it is very sensitive both to oxidation and to sulphur; but it is the opinion of many metallurgists that coke, containing, say, ½ per cent. of sulphur, does not much affect the sponge or the metal melted in the cupola.

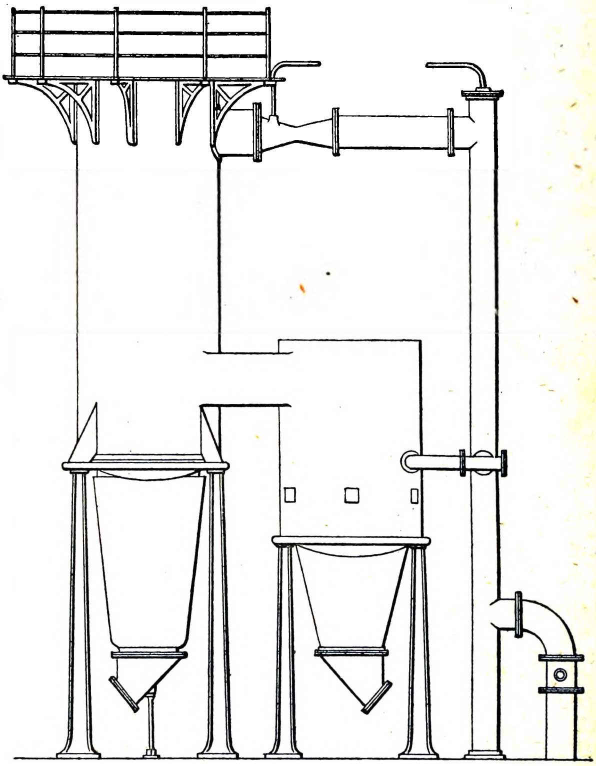
In the Blair process for the manufacture of iron sponge, the reducing furnaces when first erected were designed to work when the ore under reduction took about 30 hours to bring to a metallic state. Blair discovered, however, that by the addition of a small quantity of alkali to the carbonaceous matter mixed with the ore, the action was quickened to a remarkable extent, and that the reduction when alkali was used could be reduced to 6 hours. Subsequent investigation showed that lime in a fallen state answered well, and from its cheapness was most suitable for the purpose; the quantity required was quite insignificant when placed against the great saving in time.

In Blair's plant as at first constructed, each reducing furnace consisted of a group of 3 vertical retorts, about 3 ft. diameter and 28 ft. high, surrounded by brickwork, leaving a combustion chamber between the inside of the brickwork and the outside of the retorts, which with the outside brickwork stood upon a cast-iron entablature, supported on columns 12 ft. from the ground. Below the entablature, and forming a continuation of each retort, were wrought-iron cylinders surrounded with water jackets, and having at their lower extremity a sliding sleeve for discharging the sponge. In the top of each retort a cast-iron pipe 2 ft. in diameter and 6 ft. long was inserted, leaving a ring of 6 in. between it and the inside of the retort.

The retorts were heated externally by gas jets, the air for combustion being supplied through apertures immediately above them. When the retorts were thoroughly heated and in working order, the gas generated from the ore under reduction ascended up the inside of the pipe inserted in the top of the retort, and on meeting with air, flamed and so heated the pipe. The ore and carbonaceous matter were fed into the retort down the 6-in. ring between the retort and pipe, and, forming a narrow column heated on both sides, was thoroughly heated before reaching the wide retort below, which it entered at a uniform heat, and hence uniform reduction was the result. With the new plan of working, however, this part of the furnace would not suit, the quickened action of reduction taking place in the body of the retort below, since the ore could not be heated as quickly as the reduction took place.

Blair eventually abandoned the system of external heating and adopted that of passing a stream of hot carbonaceous oxide through the mass of ore and carbonaceous matter; he constructed a vertical retort, Figs. 1591 and 1592, made of firebricks with an external wrought-iron casing, standing upon a cast-iron entablature supported on columns; the retort is continued below by a wrought-iron cylinder with a water jacket. And at the lower extremity is a conical mouthpiece and valve, so that the iron sponge can be discharged into any receptacle placed beneath.

1591.



The lower part of the retort from where the gas is admitted is larger than the upper portion. This is done so as to form an overhang immediately above the aperture where the gas is admitted, thus forming a chamber round the mass of ore, and allowing the gas to permeate it uniformly. At the top of the retort is an outlet for the escape of the gas after passing through the ore, which is connected by a horizontal pipe to a vertical one descending to the ground, and there connected to the chimney flue. In the horizontal pipe above named a steam jet is inserted, so as to form a vacuum in the top part of the retort, to induce a regular current of gas through the ore. The retort is fed by an ordinary bell-hopper.

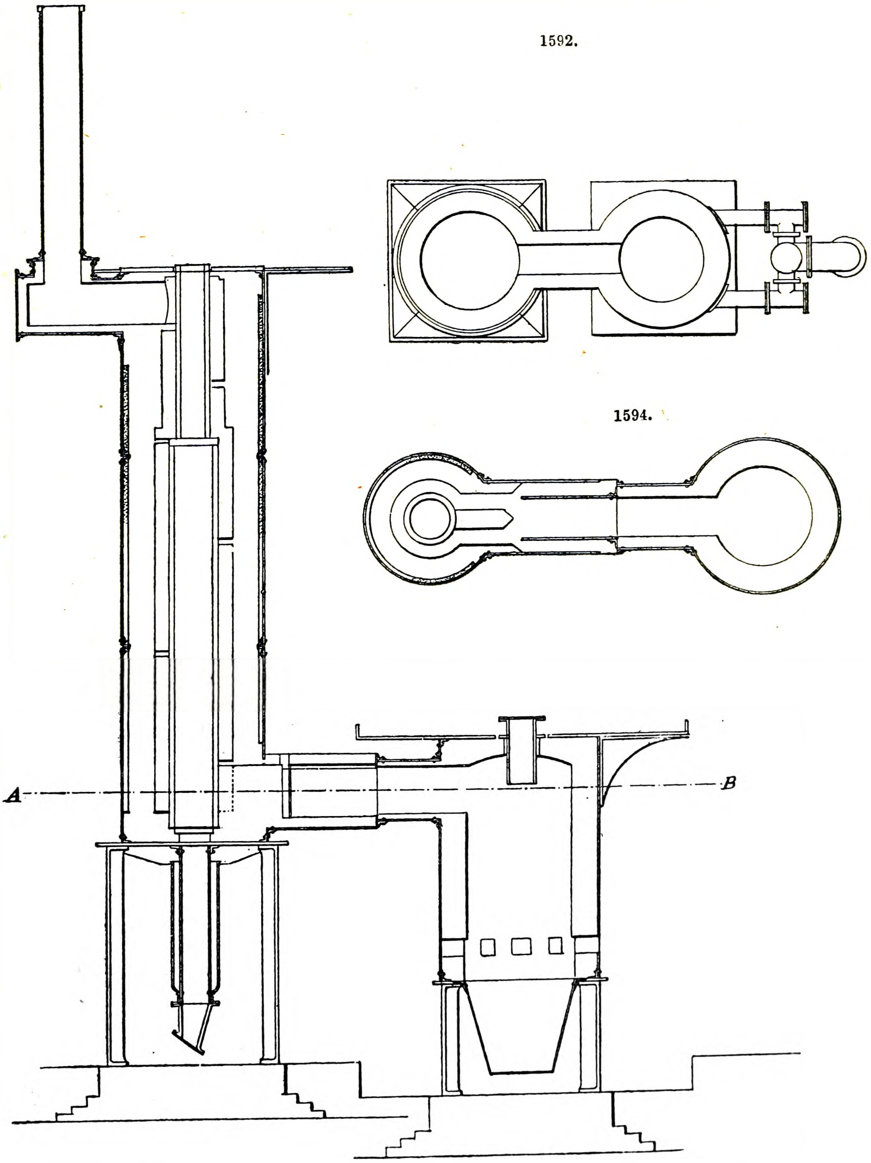
The carbonic oxide is generated in a gas-producer placed a few feet from the reducing furnace, and connected to it by a flue of sufficient capacity. The gas-producer is circular in section, formed of wrought-iron plates, lined internally with firebricks, and standing on an entablature, and suspended from it is a wrought-iron continuation, tapering to a conical discharging valve for allowing the ashes to be from time to time removed.

Apertures for admitting air for combustion in the gas-producer are placed in its circumference, fitted with slide covers to regulate the admission of air.

In the United States, Blair uses the Ponsard gas-producer, but Ireland employs the circular one just described, and finds it answers the purpose equally well.

The object of using a carbonic oxide gas is primarily to supply heat to the ore to be reduced. What reduction is effected by the gas is a secondary matter; and in this point the process differs from other attempts where carbonic oxide has been used solely for reducing the ore. It will be seen that in using the steam jet to induce a stronger current of gas through the ore under reduction, the temperature in the gas-producer will be increased, and the gas in time become hotter than required, the result being that the mass against which the gas impinges in the reducing furnace, being almost entirely metallic, would become welded together, and so interfere with the regular

1593.



1592.

1594.

working of the furnace. The gas, after passing through the reducing furnace, is still almost entirely carbonic oxide, and on passing by the steam jet becomes mixed with steam; in order to condense it, a water spray is introduced at the top of the descending flue to the chimney. A little above the air apertures in the gas-producer are two pipes connecting it and the descending flue, so that some of the gas which has already passed through the reducing furnace can be again sent through the gas-producer, and used over again, and at the same time cool down its temperature.

By regulating the slide covers of the air apertures in the gas-producer, and the damper in the flue to the chimney, an equal quantity of air and gas can be supplied to the producer. It is found, in practice, the two can be so regulated that an almost uniform temperature can be maintained in the reducing furnace.

The fuel used in the gas-producer is coke, which should be as pure as possible. In experimenting on this process with some Indian magnetic ores, very rich and pure, and containing over 70 per cent. of metallic iron, which had to be reduced with very poor coal containing 15 per cent. of ash and 10 per cent. of water, besides pyrites, Ireland devised the arrangement, Figs. 1593 and 1594. Here the inserted pipe has been abandoned, and this part of the retort divided into a number of smaller pipes, so as to present as small a column of materials to the action of the heat as possible. A small furnace, some 21 ft. in height over all, was erected on this principle, with a reducing retort about 18 in. diameter and 10 ft. 6 in. high, and a cast-iron pipe on the top $8\frac{1}{2}$ in. diameter to heat up the ore. Some 20 tons of the Indian ore has been operated on, and iron sponge of uniform and excellent quality produced, part of which has since been made into first-class tool-steel, and some of it melted into pig metal. Where the ore is rich and pure, iron sponge made from it by this process can be at once made into tool-steel. In the case of ore which is not so rich, but still suitable for steel, Ireland is of opinion the best way to utilize the sponge is to melt it in a cupola furnace into pig metal, and while in a molten state to pour it into a Siemens-Martin furnace. From the nature of the particles of iron in the sponge being so minute, it cannot be balled up in any ordinary balling furnace without considerable oxidation; it is stated, however, that if melted in a cupola furnace, the resulting metal, containing but little carbon and silicon, if conveyed in a molten state from the cupola to the puddling furnace, can be brought to nature with but very little rabbling.

LIFTS, HOISTS, AND ELEVATORS.

The various forms of lifts, hoists, and elevators are subject to constant change to suit the particular purpose for which they may be required. Those described in the present article illustrate some of the important forms which are of recent construction.

Figs. 1595 and 1596 are an elevation and plan of a fine sixty-ton steam crane, constructed by Eastons and Anderson, of London, for a large steel-works.

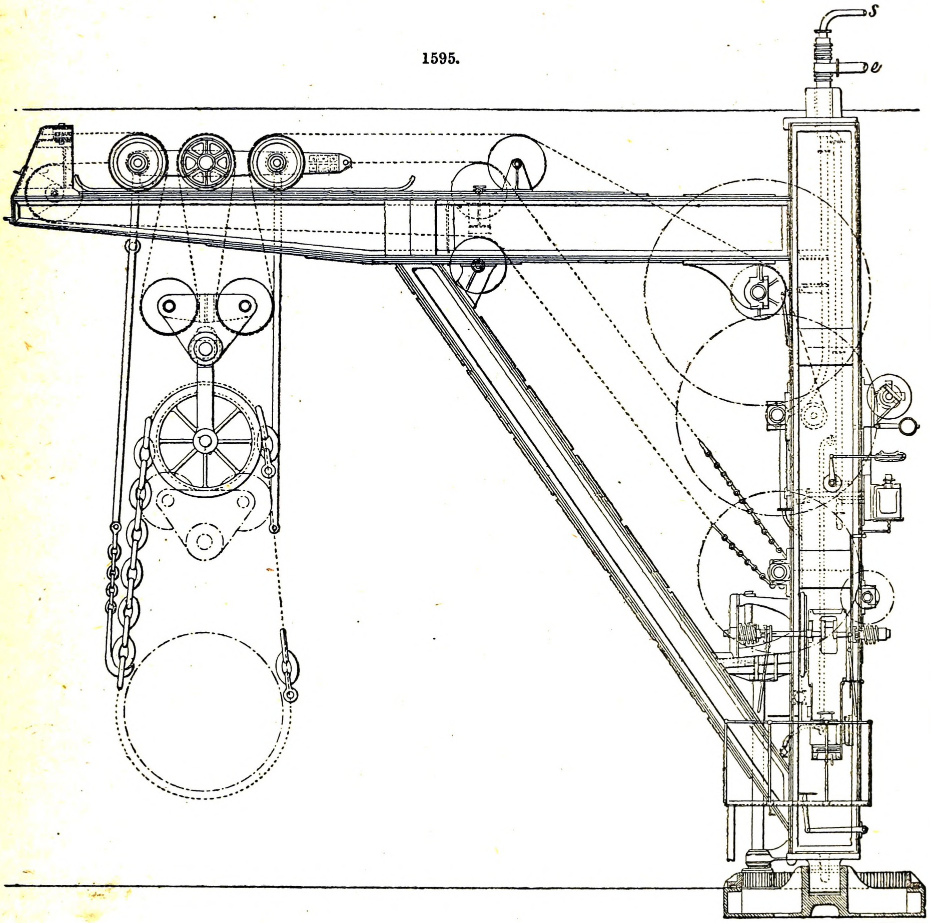
The crane is 28 ft. high with an extreme sweep of 24 ft.; it consists of a wrought-iron vertical pillar, to the upper end of which is attached a horizontal arm, supported further by a wrought-iron diagonal strut. The pillar terminates at the lower end in a cast-iron pivot 13 in. in diameter, working in a cast-iron bed plate fitted to the foundation about the foot of a power hammer standard, while the upper end is of cast steel, rotating in a socket secured into a wrought-iron crane frame which surrounds the hammer, and has already served to support the lighter cranes. This pivot is made hollow in order to allow of the passage of the steam and exhaust pipes of the engines. The hoisting gear is actuated by a pair of engines having cylinders $8\frac{1}{2}$ in. in diameter, 10 in. stroke, bolted to the back of the vertical pillar. A pinion on one end of the crank shaft gears into a train of wheels which, reducing the speed 63 to 1, communicate the motion to a pair of ordinary close-linked $1\frac{1}{8}$-in. chains, by means of a pair of recessed drums over about one-fourth of the circumference of which they lap, their free ends falling down to and coiling in the bottom of the vertical pillar, while the bight is passed over the three pairs of sheaves of the travelling carriage, and two pairs of sheaves in the falling block, the bight passing round a small horizontal sheave in the extreme end of the jib. By this means a uniform tension is always ensured on the chain, and the space required by ordinary chain barrels is saved. On the opposite end of the engine shaft is keyed a brake, actuated through connecting rods and levers by the foot of the attendant. The cross traverse and the rotation of the crane are effected by a separate single engine having a cylinder $6\frac{1}{4}$ in. in diameter, 8 in. stroke, with a small fly-wheel and link motion. On each end of the crank shaft, and running loose on it, is fitted a worm capable of being thrown into gear by a clutch, an conveniently arranged spring hand-lever.

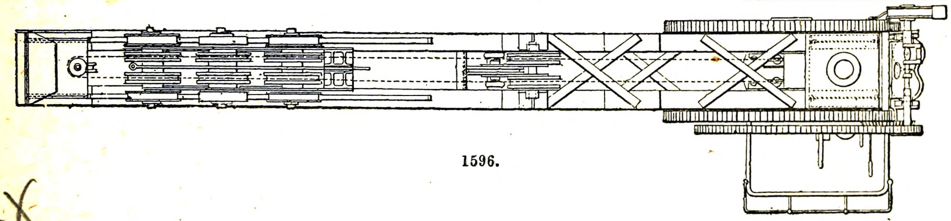
The cross traverse worm gears into a train of wheels 240 to 1, which gives motion to a spiked pulley and by its means to a short pitched chain coupled to an ordinary $1\frac{1}{8}$-in. chain, which, passing over suitable pulleys, has either end shackled to the traversing carriage. The worm for rotating the crane actuates a train of wheels 133 to 1, and communicates motion to a pinion, engaging into an internal annular segment, bolted to the base plate carrying the lower pivot of the crane. All the motions are controlled by one man from a small platform secured to one side of the vertical pillar, inside of which the steam and exhaust pipes are also arranged. For the purpose of turning the forging, strong claw chains hang down on each side of the falling block and hook into the $2\frac{5}{8}$-in. chain, in the bight of which the object to be forged is laid.

Fig. 1597 represents a steam derrick crane, designed and erected at Renfrew by Forrest and Barr, of Glasgow, to lift and work a load of 50 tons. The jib is tubular, and is made of 2-in. boiler plate, with a plate of the same thickness running on edge two-thirds of its length, and braced diagonally with angle iron, its length is 70 ft. and it weighs 15 tons. The stays are of the same construction as the jib, the motive power of the crane is a double engine with 8-in. cylinders, which is placed in the centre of the frame, and a single cylinder engine of 9 in. for the slewing and lifting of the jib.

Travelling steam cranes form a considerable proportion of the lifts employed in dealing with heavy weights upon contractors, dock and similar works, and they are usually made so that the weight of the boiler and its fittings balance the jib, whilst the engine maintains equilibrium in the centre over the travelling platform. Fig. 1598 is a side elevation of a crane of this description made by T. Smith, of Rodley, near Leeds. Fig. 1599 being an end view on a much enlarged scale. The design whilst presenting no very novel features is very compact and satisfactory. The proportions are good, whilst the arrangements for enabling the attendants to work the acting levers and attend to the machine are excellent.

1595.



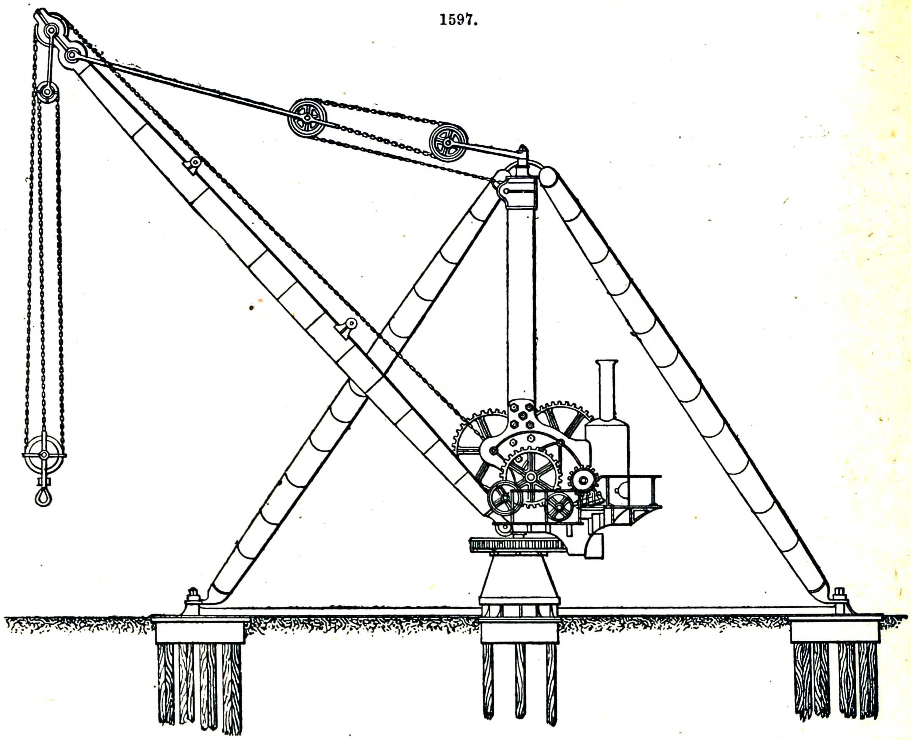


1596.

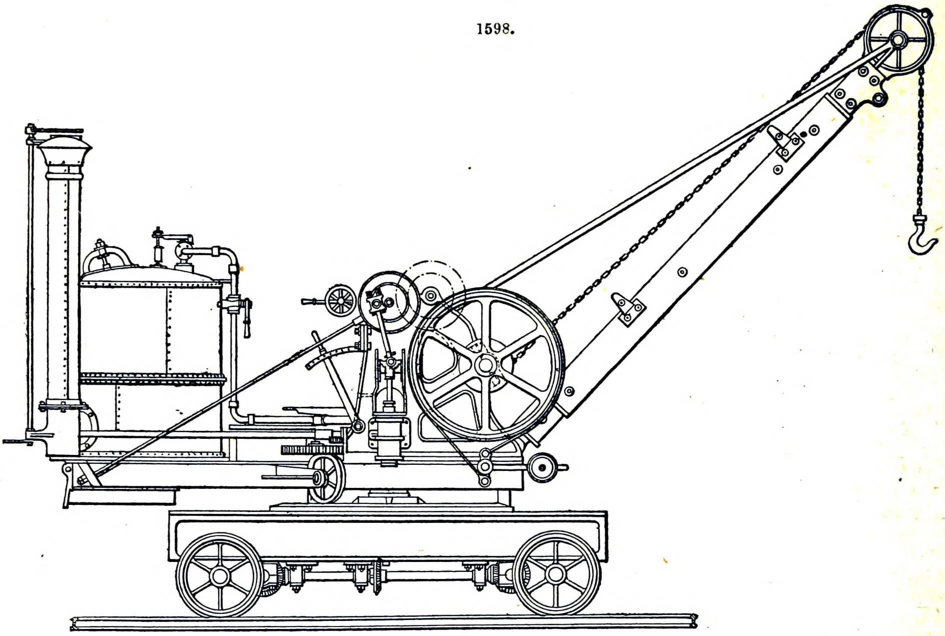
Figs. 1600 and 1601 are the side and end elevations of what is termed a radiating Steam Hercules, used at the Jersey Harbour Works under Imrie Bell; this, as will be seen, radiates on a back pivot; the radiating framework bears upon six wheels, working on a steel rail bent in the form of a segment of a circle, the chord of the arc of radiation being 50 ft. The wheels, cast of crucible steel, are placed underneath the front frame; the load, consisting of 15-ton blocks, is lifted in the bite of a 1-in. chain, the carriage supporting the pulley being racked in and out over the girders by means of an endless steel wire rope. The whole machine is propelled along a line of way having a gauge of 24 ft.; there is thus sufficient space, as well as headway, for the passage underneath of locomotives and trucks conveying blocks to the extreme end of the work, where the latter are to be lifted by the Hercules before being laid in position. All the motions for propulsion, lifting, and lowering blocks, and racking the carriage in and out, are given by a pair of horizontal engines, which, with their vertical boiler and feed tank, serve to counterbalance the overhang; any additional balance required being placed in the tank or on the tail end of the machine. These various motions are under the easy control of one man, who is also able to attend to the firing of the boiler.

The timber is of pitch pine, and the ties of good tough iron. The framing is perfectly strutted, and braced in every direction, so as to obviate any risk of failure. The strains of every strut and tie were carefully calculated, so that, although the machine is a very light one for the work it is called upon to perform, it has been found very steady in actual operation. It also works with great ease.

1597.



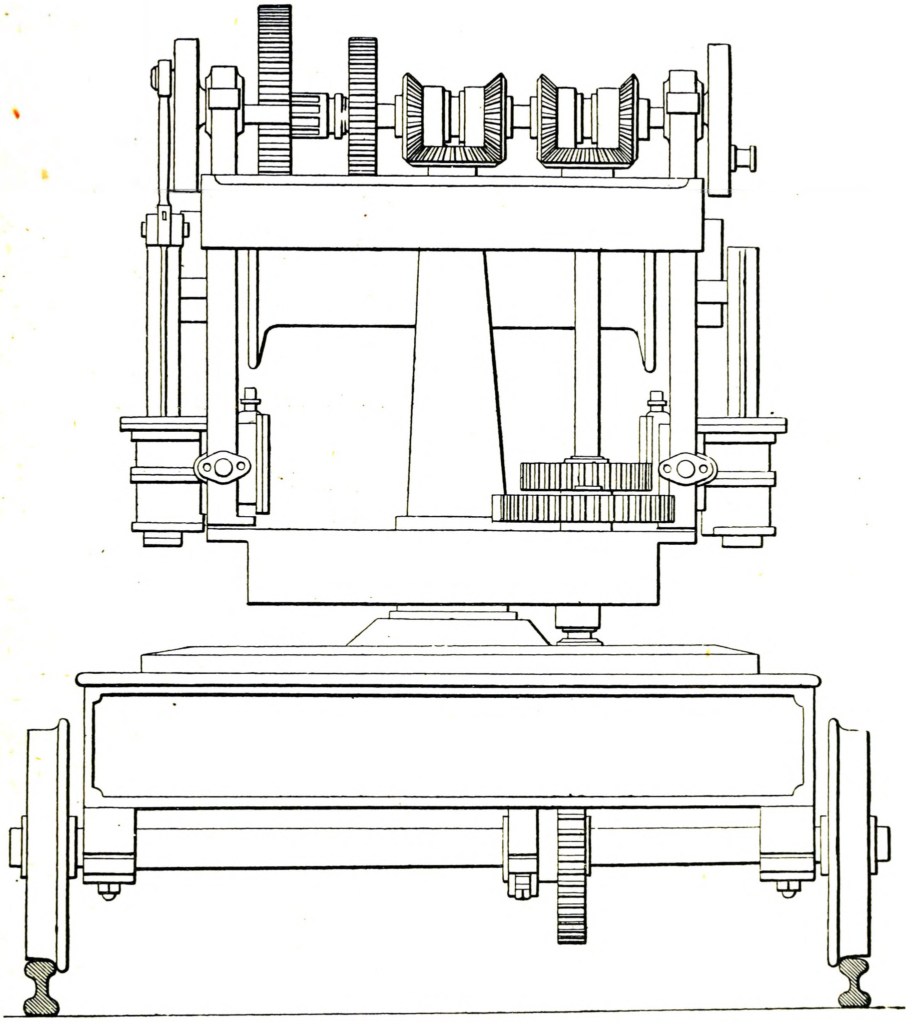
1598.



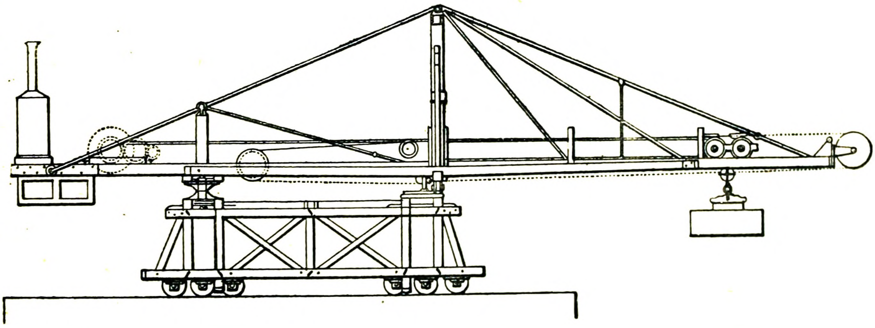
The test load of 50 tons was lifted and swung round at a radius of 46 ft. from centre, without the crane showing the slightest perceptible deflection. The snatch block weighs over 2 tons, to ensure the overhauling of the chain. 400

Figs. 1602 to 1606 are of an automatic self-sustaining crane by T. Thomas, of Merthyr Tydvil; Fig. 1602 represents in horizontal section a hand-worked lift, suitable for warehouses, hotels, and the like, where a heavy load is to be raised or lowered. To one end of a horizontal shaft A, working in fixed bearings D′ and D″, a pulley C is fixed; over this pulley an endless chain or rope is passed, by drawing down one or other sides of which, motion in different directions is given to the pulley C and shaft A. The pulley end of the shaft works directly in its bearing D″, but the other end takes into a sleeve, a contracted part of which constitutes the neck at that end of the shaft which works in the bearing D′. Thus the end of the shaft carrying the pulley can both rotate and slide, while the sleeve constituting the other end can rotate but cannot slide in its bearing D′. To the end of the sleeve a hard brass nut F is fixed, having a quick-threaded double screw formed in it; the part of the shaft A fitting in this nut has a corresponding quick-threaded

1599.

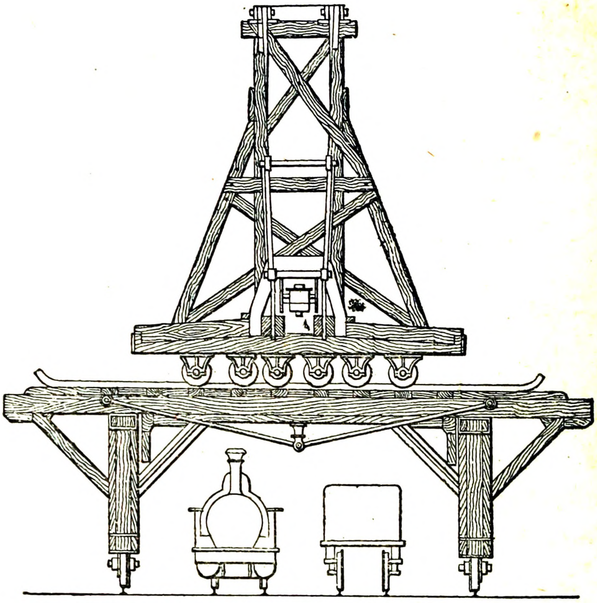


1600.



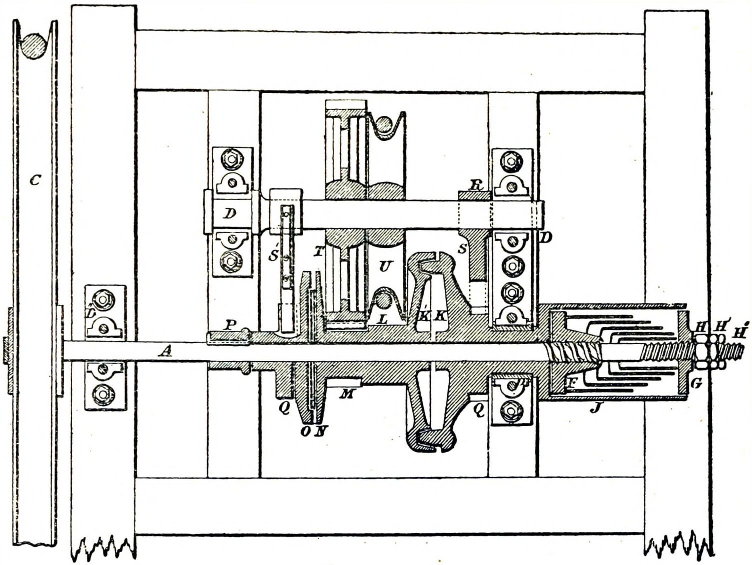
screw, the shaft and nut thus constituting a screw-box and screw engaged with one another. When the shaft is turned in a direction proper to drive home a screw, the sleeve being at the same time stationary, the screw advances in the sleeve, the neck of the shaft at the pulley end permitting of a sliding motion in the shaft A. The chain or rope by which the load is raised or lowered runs in a sheave U, keyed on a countershaft D, and is connected with the driving shaft A by a spur wheel T working in a pinion M, which forms part of a drum L working freely on the shaft A. This drum has at each end a disc, the disc K′, at the end the least distant from the pulley end of the shaft A, being larger than the other. The face of this large disc K′ is opposed to another of the same size K carried by the sleeve. The sleeve disc K has an annular projection on its face, which takes into a corresponding depression in the drum disc K′. When the larger drum disc K′ is pressed against the sleeve disc K, by means which will be described, the frictional contact of the two causes them to rotate together.

1601.



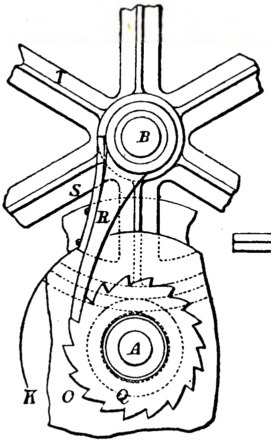
The pressure necessary to make the drum L rotate with the shaft A in a direction proper to raise the weight on the sheave U on the countershaft B is as follows. The screw end of the shaft A terminates in a reduced part, having a fine screw H″ at its end, fitted in two nuts H and H′. Sliding upon the screwed part is a strong metallic washer G, which fits loosely in a cylindrical box which forms the expanded termination of the sleeve. In this box is a volute spring, through the centre of which the shaft A passes. By screwing up the nuts H H′ on the reduced screw of the shaft, the spring can be compressed more or less between the washer G and the nut F. The compressed spring reacting on the washer G, and through it on the shaft A, draws the shaft into the sleeve by a screwing motion. The pulley end of the shaft has a collar P pinned to it, and when the shaft advances, this collar advancing with it presses the large drum disc K′ against the sleeve disc K, and produces the required friction between them to cause the drum L to rotate with the shaft. In addition to the drum L and its discs K′ and N, working loosely on the shaft A, and the collar P pinned to it, the shaft A carries another small disc O, opposed to the disc N of the drum L. This small disc O has a pad or cushion of indiarubber let into it, with a thin metallic washer on its

1602.

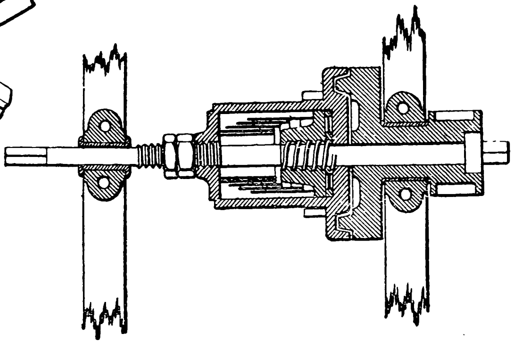


surface against the disc N. This contrivance regulates the too sudden stoppage of the descent of the weight when the friction discs grip one another. Both the sleeve disc K and the loose disc O are provided with ratchet wheels Q and Q′. Pawls S S′, which are rendered noiseless, engaging in these ratchet wheels, prevent the rotation of the sleeve and loose discs K and O, excepting in the direction proper to raise the load. When the parts are in their normal positions, and the endless rope over the pulley C is drawn down on the side proper for raising the load, the shaft A and all the parts carried by it rotate together, and when the endless rope is loosed, the load being raised remains suspended at any height to which it may have been brought, the ratchet wheels Q and Q′ and pawls S and S′ preventing the backward motion of the shaft. When it is wished to lower the load, the endless rope on the pulley C is drawn down, on the side opposite to that by which the raising motion is produced, so as to give the shaft A a backward motion. As the sleeve is prevented by the ratchet wheel P and pawl S from rotating in a backward direction, the screw of the shaft A rotates in the screwed nut F attached to the sleeve, and the shaft performs a retiring sliding motion, thereby relaxing the pressure by which the larger drum disc K′ was held against the sleeve disc K, and allowing the drum L to perform a backward or unwinding motion, under pressure of the load acting by means of the spur wheel T upon the pinion M. The small loose disc O produces by the elastic pad in its face, such an amount of friction as suffices to regulate the backward motion of the drum L, and the descent thereby of the load. Immediately the endless rope is liberated, the shaft A, by the expansion of the spring at its screwed end, is drawn through the sleeve and brass nut F, the drum L is firmly gripped, the descent of the load stopped, and the apparatus again ready for raising. The enlarged elevation, Fig. 1603, shows the construction and action of the noiseless pawls R and R′. In the countershaft B an annular groove is made in which a friction pin is placed, the bottom of the pin being made to bear forcibly against the bottom of the groove by the strong spring S on the upper side of the pawl. Over the acting end of each pawl is a stop for limiting its raising motion. When the lift is raising the load, the countershaft B is sufficient to cause the pawl R to be lifted from its ratchet wheel Q and bear against the stop. As soon as the motion of the shaft B is reversed for lowering the load the pawl R falls, and, engaging with the ratchet wheel, prevents the backward motion of the part to which the ratchet wheel is connected. Both pawls R and R′, Fig. 1602, act simultaneously. The

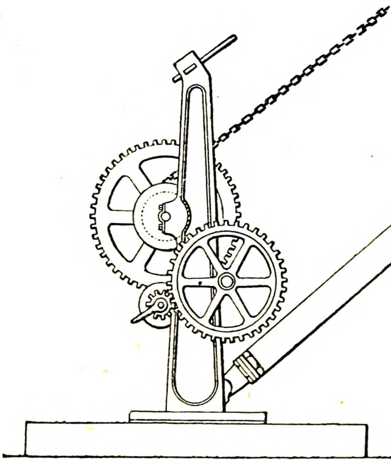
1603.



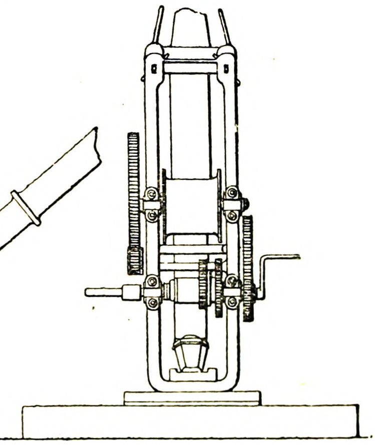
1604.



1605.



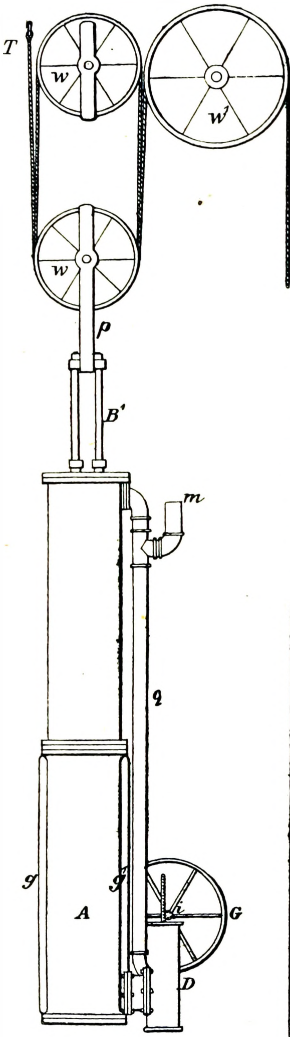
1606.



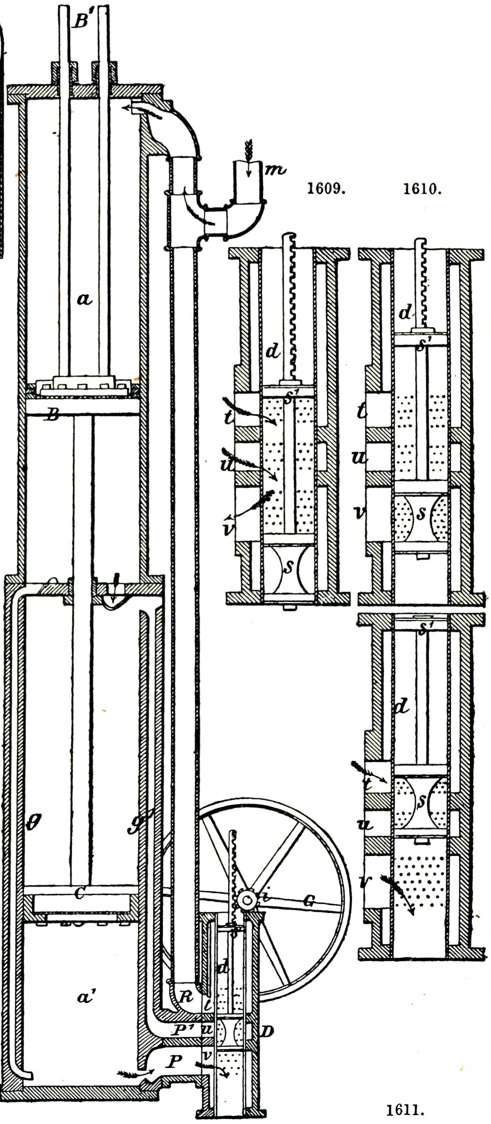
engaging of the pawls with and the disengaging of them from their ratchet wheels is automatically effected, and the ratchet mechanism is noiseless. Figs. 1604 to 1606 show the form in which the principle is applied to hand cranes.

Fig. 1607 is an outline elevation of Baldwin's lift made by Otis Brothers, of New York. Fig. 1608 is a sectional elevation, to an enlarged scale, of the cylinder piston valves, and connections of Fig. 1607; and Figs. 1609 to 1611 are sectional views, to a somewhat larger scale, of the valve devices of Fig. 1608, showing the positions of the valves as adjusted for different purposes.

1607.



1608.



A portion of the lifting rope is represented at T. This rope passes over the pulley in the usual way, and thence any desired number of times round the fixed and movable pulleys W W', of which more or less may be used, as desired, and its end is made secure. The movable pulleys W are connected by a stirrup *p* with the double piston stem B', which latter, passing through stuffing boxes into the cylinder A, is connected at its opposite end with the double piston B C. The cylinder A is made in two parts, or is divided into two compartments or chambers *a a'* by means of a transverse diaphragm, at or about midway between its two ends. The piston heads B C work one in each chamber. Both are attached to the same intermediate stem, so as to receive the same motions. The stem passes through a stuffing box, and in the diaphragm is a port opened and closed by any suitable form of valve. Supply and discharge ports P P^1 are made near the ends of the cylinder A.

The valve case D has a valve chamber *d*, of cylindrical form and lined; in the lining are perforations covering the ports $t\ u\ v$. The port has a pipe communication P with the cylinder port A^1. The port u, by a pipe or passage P', communicates with a cylinder port at the upper end of the chamber a', and the port R t is connected by a pipe P^2 with the cylinder port A^2.

In the valve chamber D are arranged a series of disc-shaped valves, $s\ s'$, on a common stem. These valves are provided with cup-leather packing, and the stems project outside of the valve case, so that the valves can be shifted by rack and pinion i. Water under pressure is admitted at m.

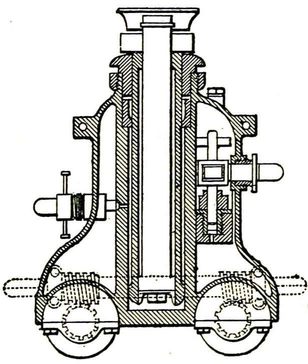
The valves in the valve case D receive their motion, through a rack and pinion i, from an operating wheel G, which is moved so as properly to shift the valves by an operating cord in the car. A hand hole, covered by a cap, is provided in the side of the cylinder A near the central diaphragm, for convenience in packing the stem and the piston head B. The lower open end of the valve chamber constitutes a waste port. The apparatus has also an open water passage g, from the chamber a near the diaphragm, to the chamber a', below or outside of the utmost point of motion of the piston head C.

When the operator in the car desires to raise the car while empty or with only a light load, he works his operating cord so as to bring the valves in the position Fig. 1608.

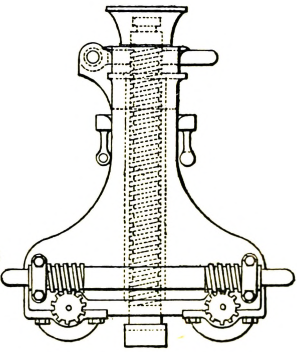
Both chambers $a\ a'$ are presumed to be full of water under pressure, as also the communicating pipes. Full water pressure will then be effective on the upper side of the piston head B, and water below the piston head C will flow out freely at v. The valve s prevents the supply from escaping at the waste port below it. Water from below the piston head B will open a valve indicated by an arrow in the upper part of the case a', and flow through the port so as to fill the space vacated by the piston C as it moves downward, the latter acting, perhaps, somewhat as a pump piston to draw the water through. The residue, if any, of water under B will pass through g to the waste port. To work the apparatus with maximum effect in raising heavy loads, the wheel G is turned so as to shift the valves to the position Fig. 1610. In this adjustment the ports t and u are brought into communication, and water in the pipe R, which is continuously under pressure, is free to pass from the port t between the valves s and s', through port u, and into pipe P', and by port g' into the upper end of the lower cylinder or chamber, and above the piston head C. Water pressure will then act effectively on top of the piston head B, as before; also, the water pressure, entering at g', will close the middle valve and act with its full force on the upper side of the piston head C, the water below B escaping by g and P as before, and water below C escaping at P, in both cases without resistance. The effective force of the water pressure is thus obtained on two cylinders instead of one, practically doubling the power of the apparatus.

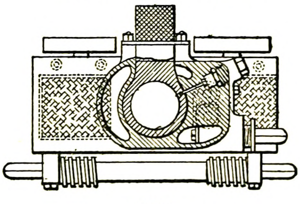
To lower the car, the valves are shifted to the position Fig. 1609. In this adjustment the valve s is below the escape port, so that the waste is entirely cut off; also, both ports u and t are brought into communication with the port v. The car, then being sufficiently heavy, or being counterweighted, comes down by its own gravity. Water above the two piston heads flows by ports $t\ u$ into the chamber a' below the lower piston C, and a portion of it passes up g into the space below the upper piston B. By raising the valves a little, the port v can be partially closed, and the circulation of water from above to below the pistons can thereby be so choked as to prevent a too rapid descent of the car, should such danger occur. To stop the car at any time it is only necessary to bring the valves to the position Fig. 1611. The discharge is closed by the valve s, and the circulation from above the pistons to below them is prevented by the valve s'. In all the adjustments described, the valves are balanced as regards water pressure; but if such is not desired, the valve s' may be omitted, the end of the valve chamber being closed by a cap made with a stuffing box for the valve stem to play through.

1612.

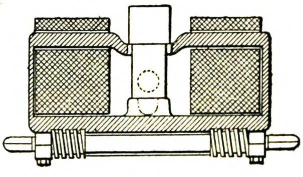


1613.





1614.

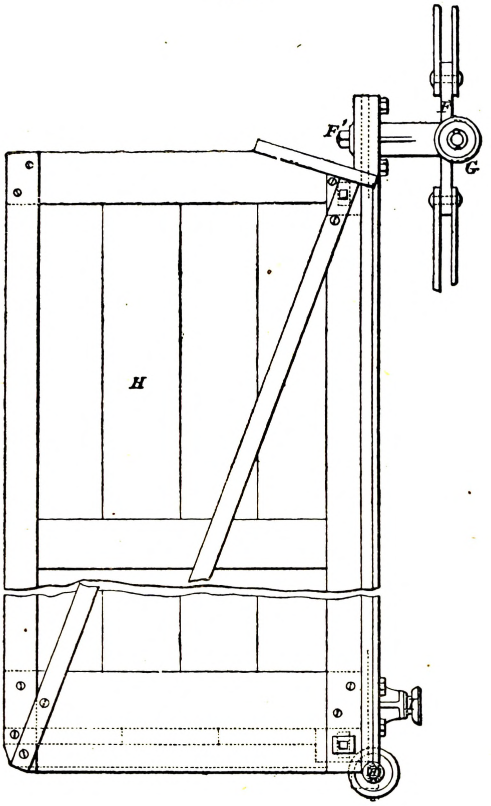


1615.

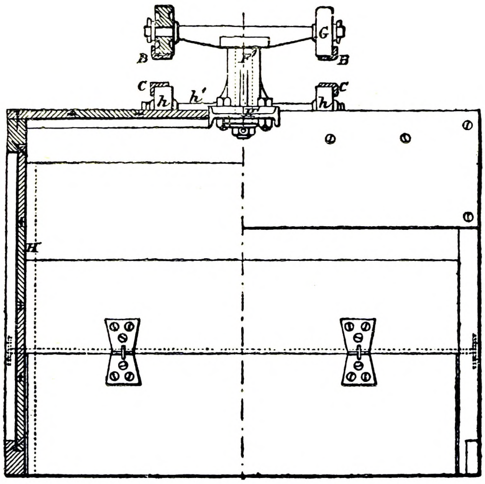
Two types of Harrison's compound jacks are shown in Figs. 1612 to 1615, one hydraulic, the other screw. The hydraulics are made to run out two-thirds their height; therefore a jack standing 22 in. when down, would stand 44 in. run out, so that they give a clear lift of 22 in., one ram rising and falling inside the other. They will lift from close to the ground, and work in any position. The pump and working parts are all contained in the jacket, which also forms the reservoir or tank, which will contain three times the amount of liquid required, thus saving time in refilling. They can easily be examined and repaired, as the valves can be taken out without touching the pump or gearing. The rams are made of fagoted iron, and the foot forms a guard or stay, thereby preventing the rams from bending or straining.

Figs. 1616 to 1619, refer to an ingenious arrangement of that class of elevators in which a series

1616.



1617.


B
G
B
F'
C
h
h'
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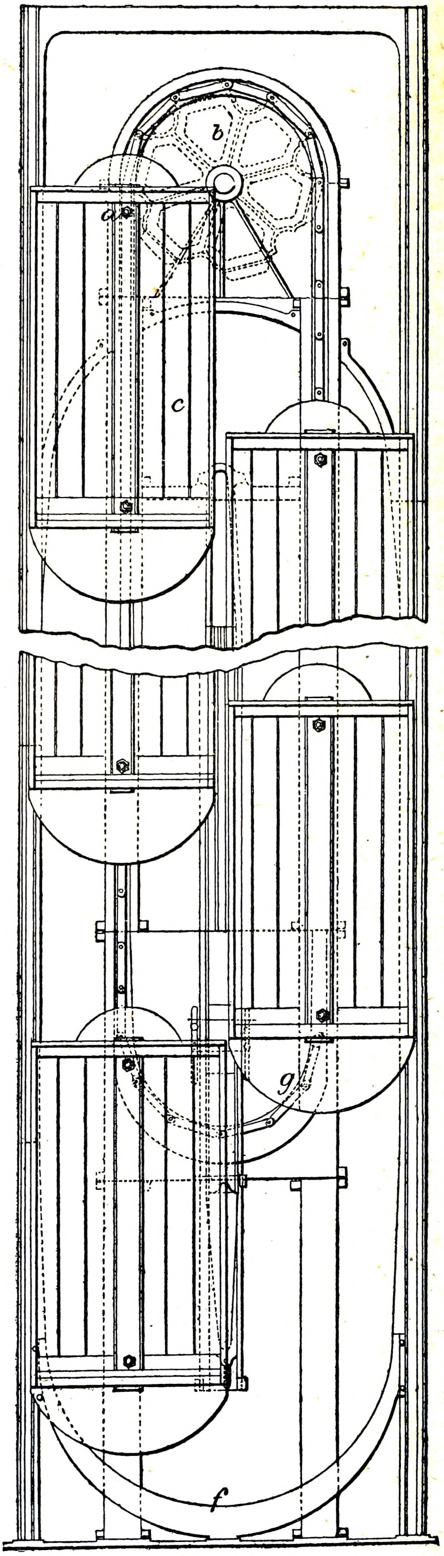
h
H

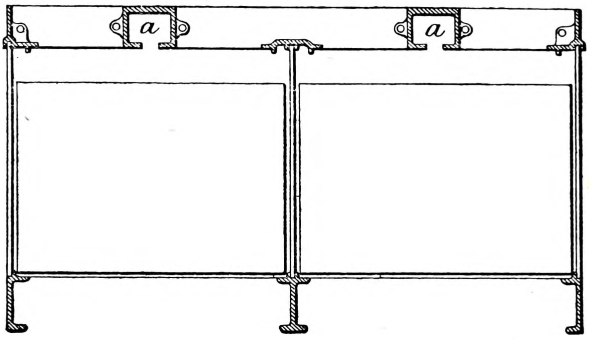
1618.



of cages suitable for receiving passengers or goods are kept in continuous motion, ascending on one side and descending on the other side, such as are commonly used in large suits of offices, hotels, and the like.

The cages are carried by an endless chain passing around chain wheels at the top and bottom, and one of these chain wheels is driven by an engine which is suitably controlled. The cages stand in front of the chain, and are suspended by means of sling links introduced into the chain at the places required. There is a sling link for each cage, and the link carries a pin projecting out from it horizontally and at right angles to the plane in which the chain travels. This pin enters an eye formed for it centrally in the back of the cage, at the upper part, and by it alone the cage hangs. Both in ascending and in descending the cage is guided by rollers or small wheels running on guides of angle iron. One pair of rollers carried by arms on the sling link controls the tendency of the upper part of the cage to fall forward, and at the same time steadies the cage laterally.

1619.



Another pair of rollers upon an axis fixed to the lower part of the cage, and running upon other angle guides, set in front of the first pair of guides, prevents the lower part of the cage tipping towards the back, which, if free, it would do, in consequence of the point of suspension being in rear of the centre of gravity of the cage. Thus the guiding of the cage is effectually provided for so long as the cage is in the straight part of its path, but when the cage is passing from side to side at the top and at the bottom, further provisions are requisite to control the lower part of the cage.

The sling link when it passes on to the chain wheel, either at the top or at the bottom, becomes securely held, and as the link is carried round, the arms bearing the rollers remain radial to the wheel, and the rollers consequently roll accurately around the guides as they curve over or under the chain wheel, but at the bottom of the cage, the wheels being on an axis which remains always horizontal, would not roll around curved guides; these guides are therefore discontinued at the top and bottom, and the control of the lower part of the cage is effected by a wheel at a suitable distance below the chain wheel. This wheel is connected with the chain wheel by gearing, so that it revolves in unison; it has recesses in its periphery, and as each cage comes round a strong stud with suitable collars upon it fixed to the back of the cage, near the bottom and vertically beneath the point of suspension, enters one of the recesses in the controlling wheel, and so the bottom of the cage becomes held and the wheel carries it round in its proper course. The guides for the lower rollers are provided with self-acting traps, near their lower ends, to allow of the passage through them of the projecting portion of the sling links by which the cages are suspended.

Fig. 1616 is a vertical section of the cages with other parts for this arrangement, and Fig. 1617 is a plan partly in section of the same; the cage H is a strong case open in front, and has an iron bar *H'*, serving as a backbone upon which it is built, and when it is intended for the conveyance of passengers it is of sufficient height to admit of a man standing erect within it.

At the upper end of the bar H', and to the back a long bearing is fixed, to receive the horizontal pin F', by which the cage is suspended; the pin is fixed in the middle of one of the links of the chain, called the sling link. It also has two arms projecting outwards from its centre at right angles to the length of the link, and at right angles to the pin, and these arms serve as axles for the guide rollers G, which roll along the backs of the angle-iron guides B B, and so control the tendency of the cage to tip forward at the top. The guides are curved round, so that a continuous bearing surface is provided for the rollers.

At the lower end of the bar of the cage a horizontal axle *h'* is fixed, and upon it are the guide rollers *h*; these roll along the front of the angle-iron guides and so control the tendency of the lower part of the cage to tip to the rear. The guide rollers *h* leave the guides C when the cage is at the top and bottom, the guides stopping short, and at these places other means are provided for controlling the lower part of the cage. The stud fixed to the bar H' at its lower end, as the cage comes round, engages with large wheels entering notches which are formed in the periphery of them for its reception.

In order to avoid the necessity for the controlling wheels and studs, the axis of the lower pair of rollers can be arranged upon a pivot on the back of the cage, kept parallel to the roller arms of the sling link by means of a pair of sprocket wheels, connected by long links in such a way that any motion of one wheel is communicated to the other. The axis of the lower rollers is continued to near the centre line of the apparatus, and has at the end a stud which at the upper and the lower end of the course of the cage enters between guides provided for it. In this arrangement the guides for the lower rollers are continued round the top and the bottom, in the same way as the guides for the top rollers are carried round from the ascending side to the descending side.

Fig. 1618 is a front elevation, and Fig. 1619 a plan of an elevator constructed in this manner.

The guides for the top guide rollers are carried by the sling link in the manner already described, with the difference that in this arrangement the guides are set closer together, an arrangement which admits of flat guides without side flanges being employed; *f* shows the guides for the bottom rollers. Lower guide rollers are carried by a movable quadrant, which is pivoted to the back of the cage, and has rollers which run upon the guides. These, like the top guides *f*, are continuous, being curved or arched round at the top and bottom. The rollers are made to roll truly around the curved course, and the requisite movement of the quadrant is obtained by connecting it with the sling link, in such manner as to keep the axles of the top and bottom guide rollers always parallel the one to the other. One sprocket wheel is mounted upon the sling link around the point of suspension of the cage, and the other upon the pivot of the quadrant.

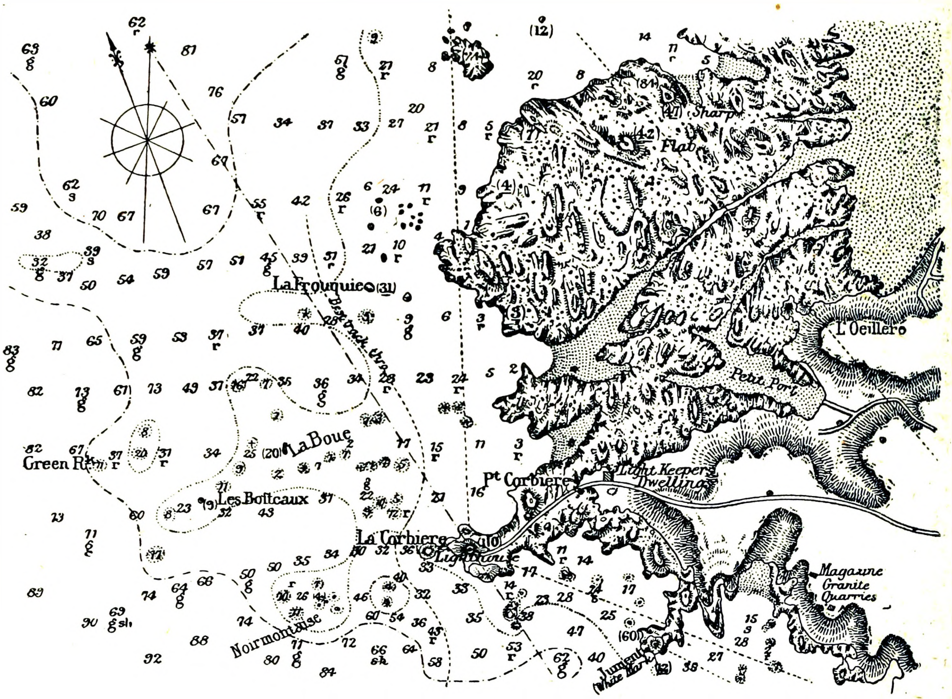
In order further to control the movement at the top and bottom and ensure the guide rollers remaining upon the guides taking a truly circular course around a central point, the quadrant is continued to the centre, where it terminates in a ⊤ or crosshead. At the ends, both at top and bottom, the guides *f* are adapted to receive this crosshead to guide it to the centre point and there retain it whilst the turning motion is taking place.

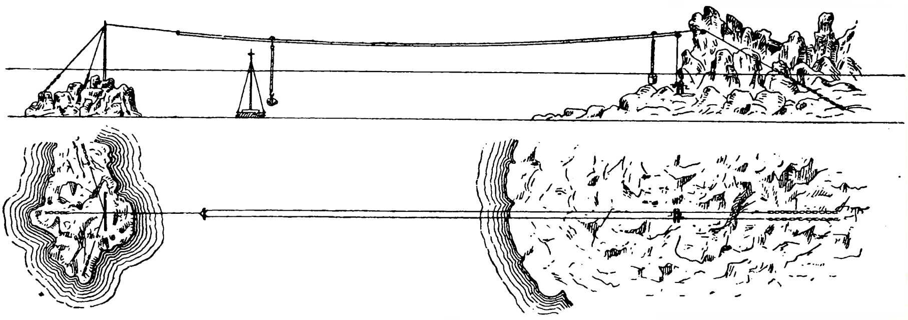
The guides have openings at the points where they are crossed by the path of the axis, from which the cage is suspended. The openings at the top need not be provided with traps. At the bottom, however, small counterbalanced traps at *g* are so arranged as to yield to the total pressure of the parts they are intended to allow to pass.

LIGHTS, BUOYS, AND BEACONS.

The Corbière Lighthouse, Jersey, is an excellent example of the use of concrete in such structures. It was constructed under the superintendence of Imrie Bell from the designs of Sir John Coode. The Corbière Rock, upon which the lighthouse is erected, lies off the south-western

1620.





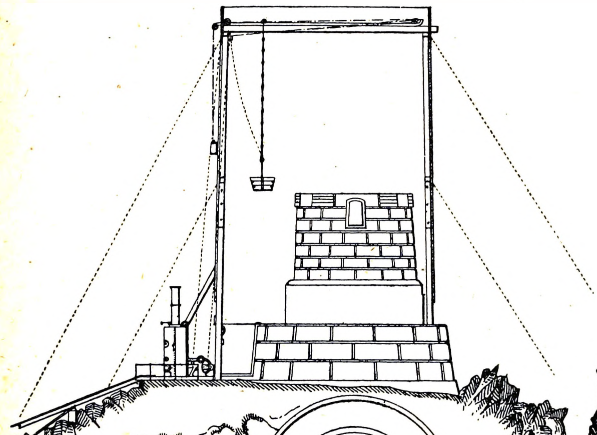
1621.

point of the island of Jersey, Fig. 1620, in latitude 49° 10′ 40″ north, longitude 2° 14′ 50″ west. It is distant from the mainland about 1600 ft., is isolated at high water of all tides, but is accessible over a ledge of rocks, shortly after half ebb tide up to nearly half flood of each tide, when the sea is smooth, not a matter of frequent occurrence in this exposed part of the island. This rendered necessary, as one of the works connected with this undertaking, the construction of a tidal causeway to ensure the safety of the lightkeepers on their passage to and from the lighthouse. The range of tide on this coast is 32 ft. at ordinary springs, and 23 ft. at ordinary neaps.

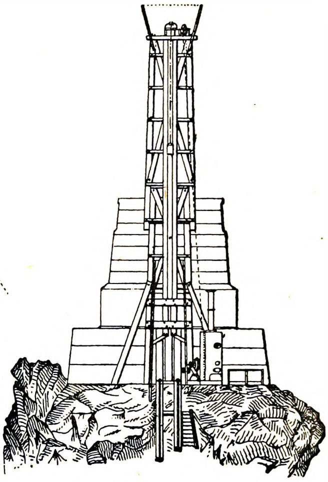
The site chosen for the lighthouse being inaccessible by land, a road of access was necessary extending over ½ mile in length; and along with this were constructed dwelling houses on the mainland for the lightkeepers, with the necessary storehouses and outbuildings.

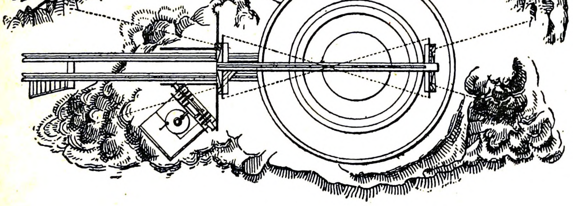
The tidal causeway exceeds ¼ mile in length, is 6 ft. in width at the top, and is formed of two side walls built of granite blocks, with a batter on the sides of 1 to 2, the height varying from 1 ft. to 8 ft.; the blocks are hammer-dressed on the face, and laid on level beds in cement mortar. The space between the walls is filled with Portland cement concrete, in the proportion of 8 parts of shingle and coarse sand to 1 part of cement; the upper 8 in. being made stronger and finer, in the increased proportion of 4 parts of shingle to 1 part of cement.

1622.

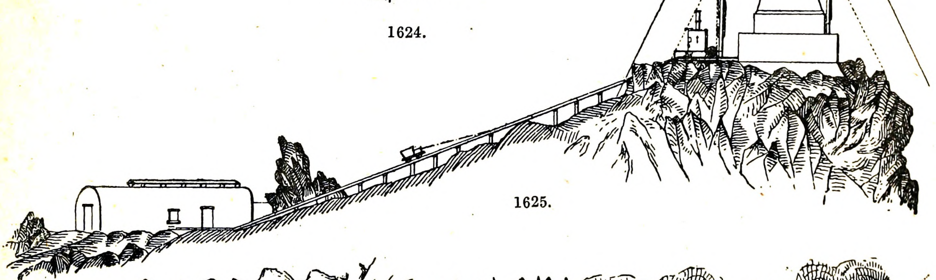


1623.

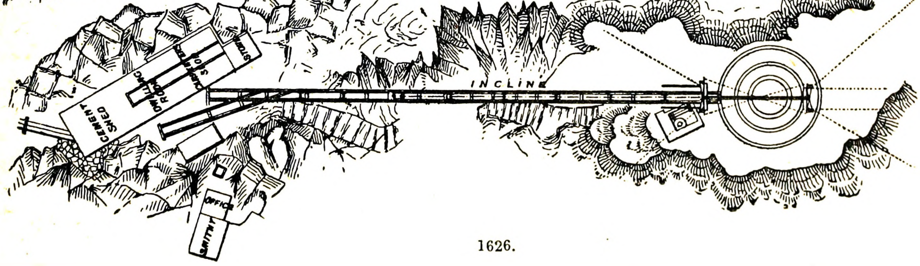




1624.



1625.



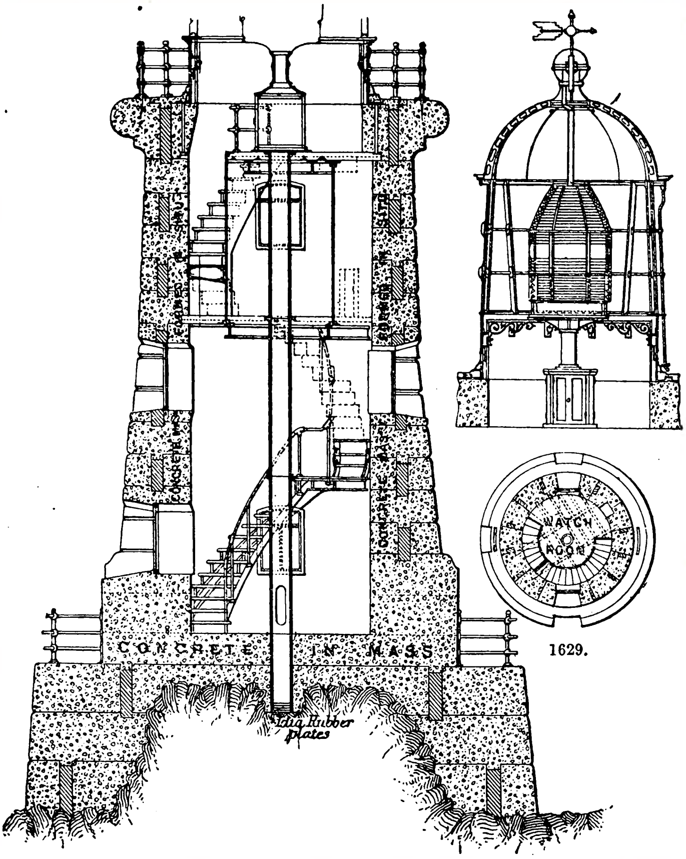
1626.

The action of the sea during gales prevents any great accumulation of seaweed upon the surface of the causeway; and a sprinkling of hot lime in calm weather, afterwards brushed off with birch brooms, is found sufficient to prevent any growth.

The landing of the material from the barges on their arrival from St. Helier, when moored in the deep-water channel, was carried out by an overhead ropeway from the main rock, at the foot of which were the stores and workshops, to the patch of rock on the opposite side of the channel, care being taken that sufficient headway was allowed for working the barges underneath, Fig. 1621.

The rope suspended between the two rocks formed the ropeway. The apparatus consisted of a single wheel with a grooved tire, which travelled on the rope, supporting a block and tackle by two side checks for adjusting the height with a hook for carrying the bag or basket of material. This wheel with tackle is pulled along the ropeway by a small endless wire rope wound round a drum, worked with a small windlass, Figs. 1630, 1631, by two men. An improvement was effected by having a double rope from the landing platform out to a little beyond the position where the barge was intended to be moored, where the ropes were fastened to a crossbar, and from thence continued to the patch of rock by a single rope, which, in order to give additional height was passed down to the rock over a pair of sheer legs. A double line of ropeway was thus formed, from the position which the barge would occupy when moored, to the landing place on the main rock. The main rope, secured to an eye-bolt lewised into the rock, was stretched from the apex of the sheer legs over the position of the barge; at this point it was secured to the centre of the crossbar, from the ends of which two ropes were fastened, and carried parallel to each other to the main rock, and firmly secured to it, after passing over the guide pulleys. At the ends of the ropes blocks and tackles were placed, to tighten or slacken them as might be required; and upon these ropeways the travelling wheels with suspended tackle and hooks for carrying the material, Figs. 1632, 1633, were run to and fro by means of the light endless wire rope, worked by the windlass. The wire rope, Fig. 1621, after two turns round the drum, passed up over a guide pulley, Figs. 1634, 1635, and was fastened to one of the travelling wheels; it was then conveyed under one of the ropeways and round a guide pulley fixed to crossbars. Returning under the other ropeway it was fixed to the other travelling wheel, and carried on to the shore or main rock, over a guide pulley, and round the drum; so that while the loading at the barge end was being proceeded with, the unloading at the shore end was going on at the same time.

1627.



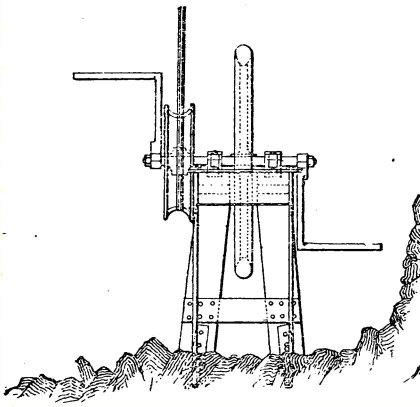
1628.

1629.

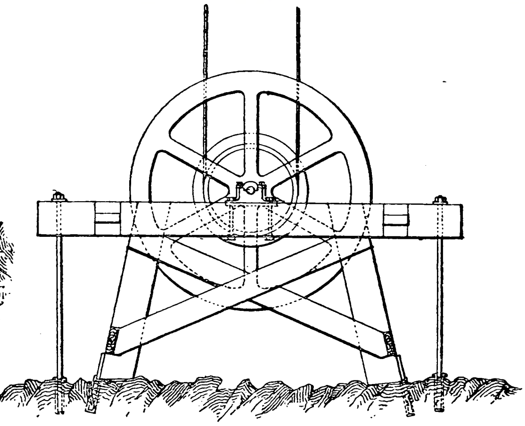
The platform upon which the lighthouse is erected is 9 ft. high, and is formed of three courses, from which the tower, with moulded base and cap, rises. This tower is surmounted by a balcony having an iron railing, above which is the lantern provided with a dioptric illuminating apparatus of the second order, showing a fixed light extending over an arc of 250°. The dark angle, of 110°, towards the shore, is occupied by a dioptric mirror.

From seaward, between the bearings of south by east through east to north by west, the light is white. Inshore of the eastern limits of the white light two sectors of red light are exhibited, one to the north-eastward, for marking the shoal ground of the Rigdon Bank, and thence landwards; the other to the south-eastward, marking the Vrachères and the adjacent dangers landwards, through angles of 32° and 38° respectively. The red arcs are produced by shades of ruby glass attached to the lantern, which is 7 ft. in height. The light is 135 ft. above the mean level of the sea, or 119 ft. above high water of ordinary spring tides, and is visible for a distance of more than 18 miles. The lamp is a pressure one, with the weights arranged below the body. The burner is of the Trinity House type, has three concentric wicks, consumes paraffin oil, and gives a light of about 200 standard candles. The lantern, by Chance, is of ordinary construction, except that the wall of the tower is carried a little higher than usual, and that the cast-iron pedestal is reduced to an equal amount. The inside diameter of the lantern pedestal is 10 ft. Outside a fog bell, weighing 5 cwt., is fixed, by means of a wrought-iron plate bracket, strengthened with angle irons, and stayed to the masonry of the tower.

1630.

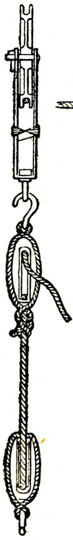


1631.

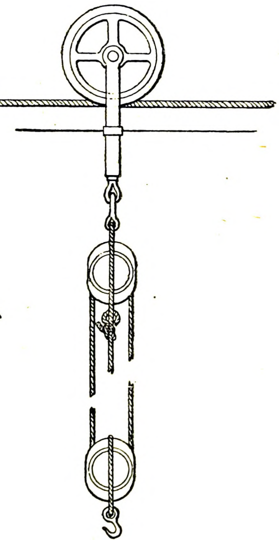


As the concrete of the tower, Figs. 1622 to 1627, was laid *in situ*, all the material had to be conveyed from the concrete mixing-floor at the level of the workshop, which was fully 50 ft. below the bottom of the platform, to the top of the rock, and then hoisted to the course under construction. To accomplish this an inclined railway, with siding on the 3-ft. gauge, was laid upon longitudinal timbers, fixed firmly to uprights secured to the rock, from the concrete-mixing platform at the depôt up to the site of the tower. Here a steam hoist was erected, and so arranged that when the trolly, with tipping skip, was hauled up to the top of the incline, it was in position for direct lift, which was effected by unhooking the chain from the trolly, and attaching it to the skip, when it was hoisted to the height required. The rod chain suspended from the traveller at the top of the scaffold, adjusted to proper length by removing or adding a link rod, to suit the courses of the masonry of the tower, was then attached to the hook of the skip, the crab chain was slightly slackened, and its hook relieved, and the skip was run forward over the centre of the tower, and the material tipped on to the banker, which completed the operation. The empty skip was drawn back into position for lowering by the counterbalance weight, the crab chain hooked to it and wound up a little, in order to relieve the rod chain which was detached, and the skip was then

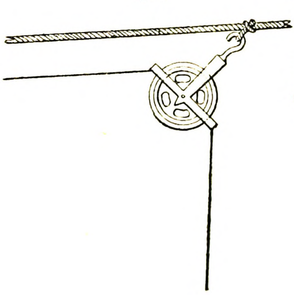
1632.



1633.



1634.



1635

lowered on to the trolly and run down the incline. During the time thus occupied another skip was being filled upon the trolly on the siding at the foot of the incline, and was ready for hauling up on the return of the empty one, an arrangement which allowed the work to go on smoothly and continuously. The scaffolding was made of timber, strutted and braced, and securely guyed with wire ropes to the rocks below.

The top of the rock was roughly quarried for the bed of the platform, leaving a core about 13 ft. in diameter and 7 ft. in height. The mould, a segment of one-eighth of the circle, 3 ft. in height, dressed on the face to a radius of 7 ft. 9 in., and a batter of 1 in 12, was fixed in place by tie bolts lewised into the rock. The concrete, composed of 6 parts of shingle and coarse sand to 1 part of Portland cement, was then thrown in to the level of the top of the segmental frame, and the operation was repeated by shifting the frame round until the course was complete. The second and upper courses were laid in a similar way. The circular platform was 29 ft. 6 in. in diameter at the top, and 9 ft. high. The chamfered joints were formed by fillets tacked on to the face of the frame, and when the work was stripped of the frames, the third day after depositing the concrete, the face presented an appearance equal to dressed ashlar, and as hard as a soft brick. Instead of dowels and joggles a batten was fixed upright at each end of the frame, so that when the concrete was filled in, and the batten removed, it left a vertical slot at each joint, about 9 in. long by 4 in. wide, the full depth of course, which was filled in, and formed part of the adjoining block, when the frame was shifted horizontally round, and again filled with concrete. A concentric channel, 9 in. broad by 4 in. deep, was left in the upper surface of each course for a similar purpose. This was filled up with concrete forming part of the course above, so that the whole structure was bound together as one stone. In order to give a smooth face to the work, care was taken that the Portland cement mortar, the proportions of which were 3 to 1, was laid close to the face of the mould, from 2 to 3 in. thick, and carried up with the concrete or rubble work at the same time, to ensure equal setting and uniform colour. To prevent the mortar adhering to the face of the mould, soap, boiled with water to the consistency of cream, and applied immediately before the work was commenced, proved most satisfactory. The face moulds, which were made of pitch pine, were first washed thoroughly clean, and then thickly painted with the soap solution by a whitewasher's brush.

Upon the top of the platform the tower, Figs. 1627 to 1629, was carried up in the same manner as previously described, with the exception that the mould frames were made to radiate from the iron centre of a frame firmly wedged and secured within the wall of the tower, building simultaneously two blocks, which formed opposite sectors, and completing the circular course in four shifts. The height of the tower and platform is 44 ft., the well of the tower is 11 ft. in diameter, and the thickness of the shell varies from 2 ft. 6 in. under the cavetto at the cap, to 4 ft. 3 in. at the plinth mouldings; the base is 5 ft. 3 in. thick. There are two floors with three landings, as the work was designed for three floors. The girders for the floors are of rolled wrought iron, and were built into the side walls as the work proceeded. The floors are of ⊥ irons resting on the girders, and built into the side walls; the spaces between, and for $1\frac{1}{2}$ in. above the irons, are filled with fine cement concrete, in the proportion of 4 parts of shingle and sand to 1 part of cement. In the centre of the tower a hollow cast-iron column, 13 in. in diameter and $\frac{5}{8}$ in. thick, in four lengths, is built into the platform; the ends of each length terminate with circular flanges, which are securely bolted together. The top length is bolted to the under side of the pedestal of the optical apparatus which it supports. The partition of the watch room is made of wrought-iron plates $\frac{5}{16}$ in. thick. There are five windows; the openings for these and the door were made by fixing wooden centres formed to the required shape and boarded over, and the concrete filled in with the courses through which they pierced. The staircase consists of two wrought-iron spiral stringers, made of flat iron, 7 in. long by $\frac{3}{8}$ in. thick, with angle-irons 2 in. by $\frac{3}{8}$ in. thick, riveted to the upper and lower edges. The stringers are firmly bolted to the floor of the tower, and to the girders and cantilevers at the landings. The risers and supports are of flat bar iron, $2\frac{1}{4}$ in. deep by $\frac{7}{16}$ in. thick, riveted to the upper angle iron of the stringers; the tread plates are of cast iron, with grating panels. The balusters are of polished wrought-iron $1\frac{1}{2}$ in. in diameter, with bright brass caps and handrails.

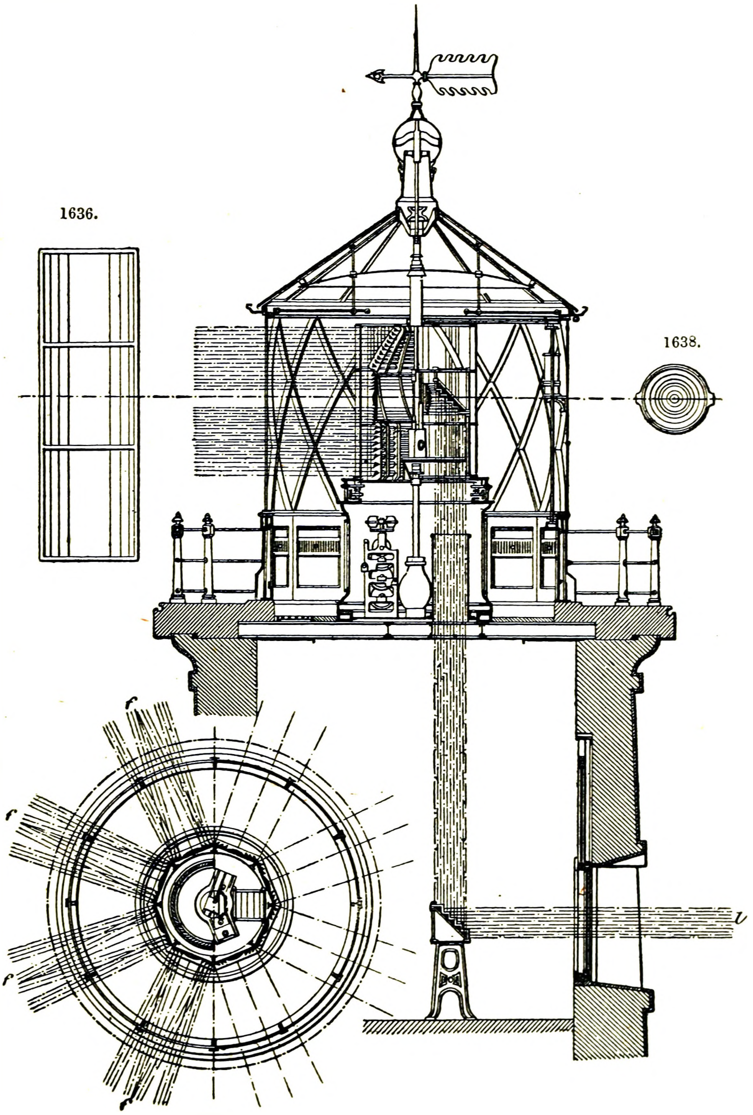
The lantern pedestal, Figs. 1627, 1628, is of cast iron, securely fastened to the masonry of the tower by twelve $1\frac{1}{4}$ in. holding-down bolts, 3 ft. long. The inside is lagged with American yellow pine, and fitted with brass circular ventilators, the service galleries are of cast iron, the incline framing for supporting the roof is of wrought iron, faced with gun-metal, the cupola is of copper double lined, surmounted by a copper revolving cowl with vane. An outside ladder is fixed to the roof, and a lightning conductor is carried to the foot of the tower, and down a fissure in the rocks beneath into a deep pool, which is submerged at high water of all tides.

After the removal of the inclined railway and scaffolding of the tower, the approach was formed by cutting steps out of the rock, and in some instances by forming them of concrete, protected to windward by a rough-built rubble wall in cement mortar, with stones quarried from the adjacent rocks, with which it corresponded in appearance when finished.

The quantity of paraffin consumed was 2·26 gallons in every twenty-four hours.

The great desideratum in a lighthouse luminary would appear to be a maximum intensity, combined with perfect focussing compactness in the optical apparatus employed, for condensing the radiant light into an intensified beam, and directing it to the sea surface. In these respects neither oil nor coal-gas flames can be considered perfect, large trials have therefore been made of the electric light. J. N. Douglass in 1879 made a most able communication to the Inst. C.E., detailing the results of its application at various places, and from this we extract the following particulars.

Fig. 1636 is an elevation of one of the panels, Fig. 1637 section of the lantern and part of the tower, Fig. 1638 plan of the holophote, and Fig. 1639 plan of the lantern of the Souter Point lighthouse, where the electric light was first shown in 1871; it is situated about midway between the entrances to the rivers Tyne and Wear. The buildings comprise tower, engine and boiler house, coke store, workshop, store-room, and dwellings for five men. The tower is 55 ft. high, surmounted with a cylindrical helically framed lantern 12 ft. in diameter, having the focal plane of the light 150 ft. above high water of ordinary spring tides. The buildings are all constructed in rubble masonry in mortar, and stuccoed in Portland cement. As no fresh water was to be found on or near the site for the boilers, an asphalted rain-catch, 2100 sq. yds. in area, was laid around the dwellings, and four underground storage tanks, with two cooling ponds, were constructed. The engines were provided with condensers, fire pump, and two Cornish boilers, and a fog-horn apparatus.


1637.

1636.

1638.

1639.

The magneto-electric machines and fog-signal apparatus were originally driven by frictional gearing; but this was found to wear rapidly, and caused considerable trouble. It has therefore been replaced by shafting, pulleys, and leather driving-belts. When, however, the atmosphere is impaired for the transmission of light, by rain, mist, or snow, both machines are worked, and with fog occurring, either by night or by day, the fog signal is sounded.

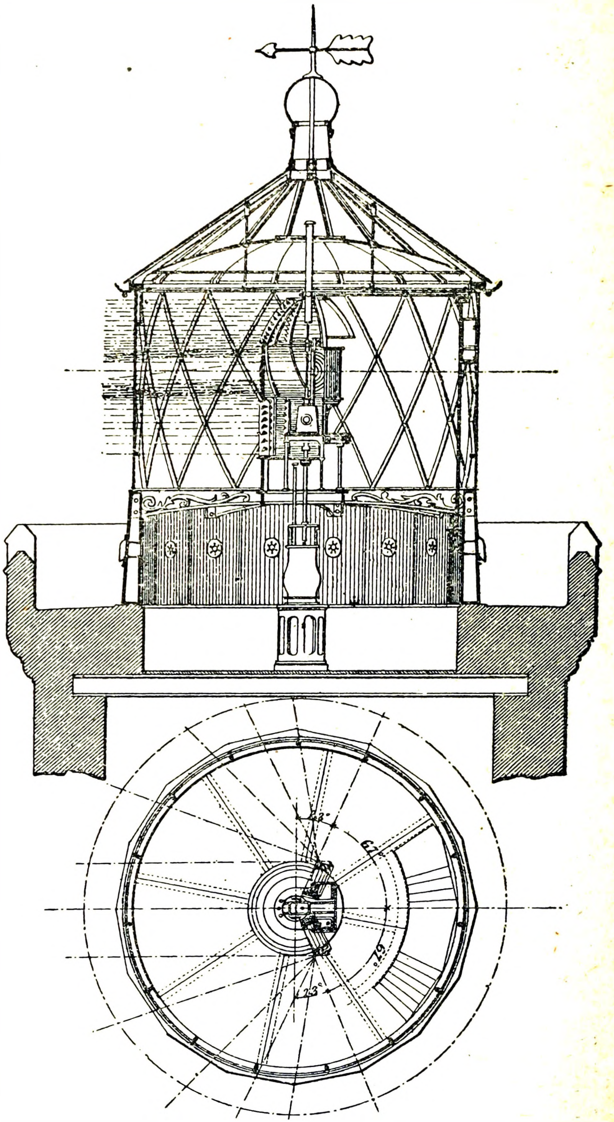
Either or both of the magneto-electric machines and the fog signal can be worked by either engine and one boiler, so that the complete apparatus for the production of the electric light is in duplicate. The conducting cables between the magneto-electric machines and the lamp in the lantern are 175 ft. in length, and consist of the following;—Between each magneto-electric machine and a current changer fixed against the wall of the engine room, there are two copper wires ¼ in. in diameter; and from the current changer to the lamp in the lantern there are three insulated cables, one of nineteen copper wires, No. 16 B. W. G., and two of seven wires No. 14. With the current from one machine, the larger and one small cable are used, the larger cable going to the upper carbon, and the smaller cable to the electro-magnet of the lamp and lower carbon. With the second machine added, one current is coupled with that of the other machine and sent through the larger cable to the upper carbon, and the other current is sent through the third cable direct to the lower carbon, without passing through the electro-magnet. With this arrangement no alteration in the strength of the electro-magnet of the lamp occurs, in altering the light from single to double power, or from double to single power, and, consequently, no readjustment of the lamp with these changes of intensity is necessary.

As an additional precaution, an oil lamp of four wicks has been fitted to the optical apparatus, and arranged so that its flame can be promptly brought into focus in the case of a total failure of the electric apparatus.

The optical apparatus consists of a portion of a dioptric apparatus of the third order of Fresnel for fixed light, having a focal distance of 500 mm. in the central horizontal plane. It is referred to at length p. 843.

An improvement was made by Douglass in the arrangement of the turntable of this apparatus. This consisted in the enlargement of the roller-path to the full diameter of the apparatus, by which, besides increased steadiness and precision, access to the interior of the optical apparatus is obtained at all times, without the necessity of stopping it, as is usually the case, and thus altering for the time the exact character of the light. A lower reflecting light from the same luminary as the upper light is shown from a window in the tower, 22 ft. below the upper light, for marking changes in Sunderland Bay, distant 6 miles.

1640.



Scale ⅛" Inch 1 Foot

1641.

The fog signal consists of a pair of Holmes's fog trumpets, with their mouths directed seaward, and their axes separated 90°. These trumpets are fixed 87 ft. seaward of the lighthouse, at an elevation of 85 ft. above high water, and are sounded by air compressed to 30 lb. a sq. in., by a pair of pumps worked by the engines. The compressed air is sent through an underground pipe to a receiver in the signal house, on which is fitted an automatic apparatus, to regulate the intervals and duration of the blasts. The apparatus is arranged to sound every forty-five seconds, the duration of each blast being four seconds, and the silent interval forty-one seconds. It has lately been necessary to replace the reed trumpets of Holmes by a more powerful Siren trumpet, sounded by air compressed by an additional engine and boiler of twenty effective horse-power. It will thus be seen that the motive power required for a first-class fog signal is sufficient for the production of an electric light, at the focus of the optical apparatus with an intensity of about 25,000 candles.

At the South Foreland there are two fixed coast lights whose relative positions are E. by S., and W. by N. magnetic, and their distance apart 449 yards. The focal plane of the low light is 275 ft., and that of the high light 372 ft. above high water of ordinary spring tides.

Figs. 1640, 1641 are of the South Foreland lighthouse arrangements for utilizing the electric light. The machinery and apparatus consist of a pair of horizontal condensing engines, each of 10 horse-power, a pair of Cornish boilers, four of Holmes's improved magneto-electric machines, of the same model as those described for Souter Point; together with the necessary shafting, pulleys, and belts, for driving any two or all of the magneto-electric machines with either engine.

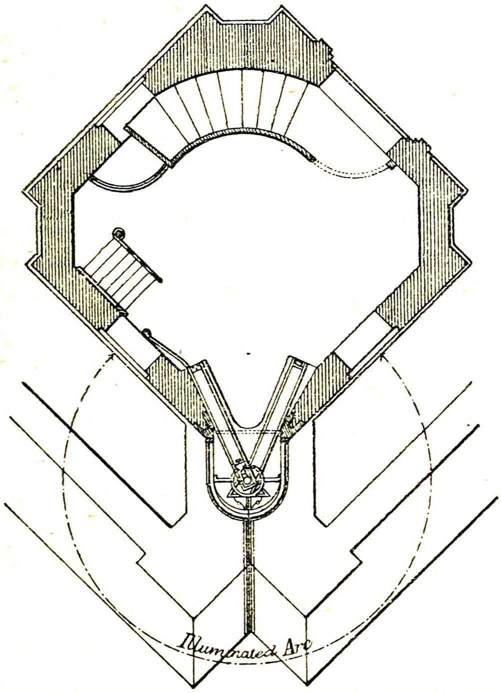
The conducting cables between the magneto-electric machines and electric lamp in each lantern, together with the current changer, are of the same form and dimensions as those described at p. 835. The conducting cables are laid underground, imbedded in asphalte in 6-in. glazed stoneware pipes. The distance between the magneto-electric machines and the lamp in the lantern of the high lighthouse is 694 ft., and between the magneto-electric machines and the lamp in the lantern of the low lighthouse, 592 ft. The old lanterns were utilized for the electric light by the removal of the vertical framing and flat glass, helical framing and cylindrical glass being substituted.

At the Lizard Light the machines are arranged to be driven by a leather belt off a pulley on the fly-wheel shaft of the caloric engines, the speed of the engines being sixty revolutions a minute, and that of the dynamo-electric machines eight hundred and fifty. Each pair of dynamo-electric machines is fitted and bolted to the same cast-iron base plate, together with an intermediate pulley frame provided with two pulleys. The axle of each machine is connected to the axle of the pulley frame by a faced disc coupling and four bolts, and thus no unnecessary strain in driving is incurred at the axle or bearings of the dynamo-electric machines. During clear weather the current from one machine is sent to each lantern; a second caloric engine, with banked fire, and its two dynamo-electric machines, being kept in readiness for immediate use. When the atmosphere is impaired by rain, mist, or snow for the transmission of light, the second engine is started, with its two dynamo-electric machines, and the current from two machines coupled is sent to each tower, giving a mean intensity of each luminary in focus of about 8250 candles.

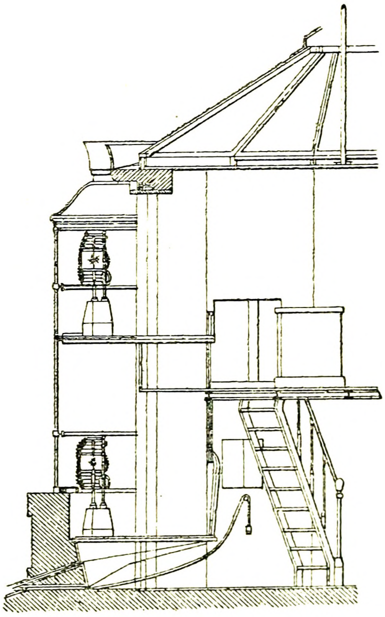
Whenever fog occurs the fog signal is sounded by one engine. With the occurrence of the fog between sunset and sunrise, and with the dynamo-electric machines going at the time, the second caloric engine is started for the fog signal, and the fire is lighted in the retort of the third engine; but if four of the dynamo-electric machines happen to be at work at the time of the fog occurring, two are taken off the light; the engine which was driving these is used for the fog signal, and the third engine is kept in readiness, with a banked fire, in case of accident to either of the other engines.

The caloric engines, Fig. 1221, are used to drive the dynamo machines. The conducting cables between the dynamo-electric machines and the lamp in each lantern, a distance of about 280 ft., consist of nineteen copper wires of No. 16 B. W. G., covered with one layer of felt tape, then insulated with pure indiarubber, and covered with a double layer of cotton tape, saturated with indiarubber solution, the cables having a diameter of 0·425 in. The conductivity of the copper wire of these cables is 90 per cent. of that of pure copper. The cables are led from the dynamo-electric machines along the surface of the walls at the upper part inside the buildings, and are carried by means of wooden suspenders secured to the walls at every 3 ft. A current changer is fixed to the wall of the engine room, and is so arranged that the current from any one of the dynamo-electric machines, or any pair of machines, may be promptly sent to the lamp in either of the lanterns. The lamps are six in number, being two for each lighthouse, and two spare. The lanterns are the improved cylindrical helically framed, first order type of the Trinity House, at first intended for first order dioptric oil lights, and consequently larger than are really necessary for accommodating dioptric apparatus for the electric light.

1642.

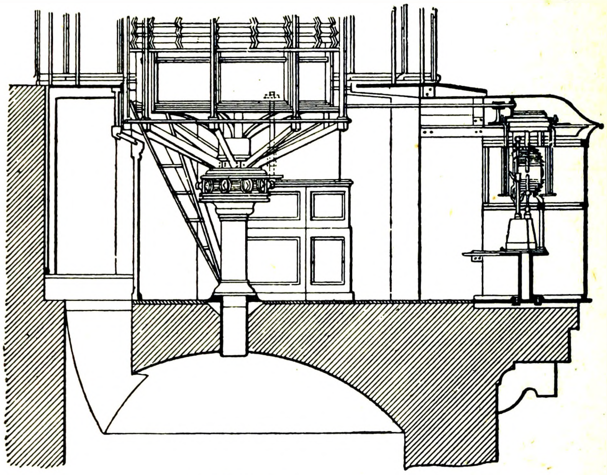


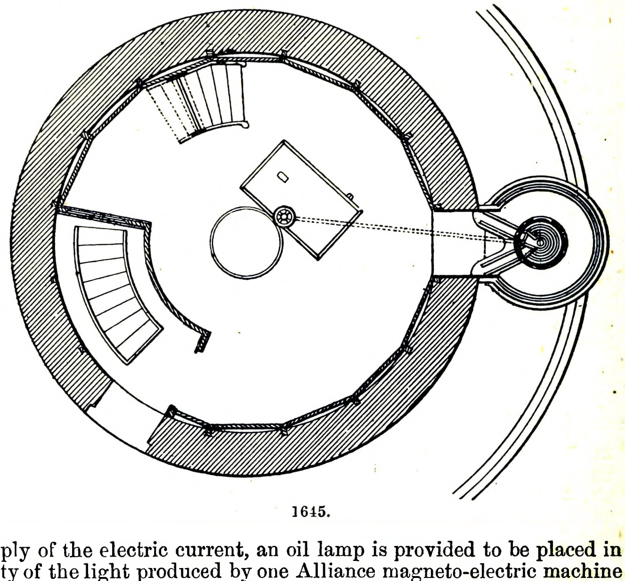
1643.



The optical apparatus for the two fixed lights, designed by Hopkinson, and manufactured by Chance Bros. and Co., is of the same dimensions and general arrangement as those at the South Foreland, and the optical apparatus for the electric light, exhibited by the British Trinity House at the Paris Exhibition, 1867, was utilized in their construction. Both lights have their focal plane 227 ft. above high water of ordinary spring tides, and illuminate a sector of sea surface of 235°, extending from the horizon to within $\frac{1}{4}$ mile of each tower. In both the landward arc of light of 125° is utilized, in the same manner as in the South Foreland apparatus, by holophotes and vertical prisms. In these the optical requirements are fulfilled very satisfactorily. A six-concentric wick mineral oil lamp is provided, and fitted to each apparatus as a stand-by, in case of accident to the electric light. The fog signal consists of a cylindrical Siren, by Douglass. Its form is a hollow drum, 6 in. in diameter by $9\frac{1}{2}$ in. long, having twelve longitudinal slits in its surface, $8\frac{1}{4}$ in. long by $\frac{1}{2}$ in. wide. The aperture or mouth of the trumpet corresponds in form and dimensions to one of these slits. As the drum is driven at a speed of forty revolutions a second, the compressed air, at a pressure of 50 lb. a square in., passing freely into the drum, is in its passage through the slits to the trumpet cut off twelve times in each revolution, thus making 480 vibrations a second. The compressed air is accumulated in two receivers, of a collective capacity of 334 cubic ft. The Siren is arranged for giving one blast of five seconds' duration every five minutes, the opening and shutting of the admission valve for the blasts being effected by gearing, worked from the shafting which drives the Siren. The cast-iron trumpet, 15 ft. long by 18 in. in diameter at the mouth, is pivoted for setting in any direction in azimuth over the illuminated arc, and it is always, when sounding and with wind blowing at the time, pointing to the windward portion of the above arc. Communication is established between the engine room and lanterns, also between each lantern and the bedroom of each lightkeeper by speaking tubes.

1644.





1645.

In the French lighthouse system in adopting electrical lighting at the Cape La Hêve lighthouses, it was found necessary to construct an engine house with coal store, workshop, raincatch, and storage tanks for water, a square room on the top of each tower for the optical apparatus, and dwellings for three additional attendants. The machinery and apparatus consist of two portable steam engines, each of 8 horse-power, and four Alliance magneto-electric machines, each containing forty-eight helices, arranged in six wheels, and fifty-six compound permanent magnets. The lanterns which surmounted the towers when oil lights were exhibited have been removed, and the electric lamps are placed in small cylindrical lanterns made about $2\frac{1}{2}$ ft. in diameter, projecting from the seaward angle of the square service room, the arc illuminated by each light being 275°, Figs. 1642, 1643, which are respectively a plan and section of the lantern and watch room. The optical instruments in each tower consist of two dioptric apparatus of the sixth order, having a focal distance in the central plane of 150 mm., placed one above the other, and similar to the arrangement adopted at Dungeness. Each optical arrangement is provided with two Serrin lamps, and, in case of accident to the supply of the electric current, an oil lamp is provided to be placed in the focus of the lens. The intensity of the light produced by one Alliance magneto-electric machine in a Serrin lamp is 200 becs, or French units, being equivalent to 1920 candles, or English units. During clear weather only one magneto-electric machine is employed for each lighthouse. With thick weather two magneto-electric machines are used. The intensity of the light from the optical apparatus with the luminary of one machine in its focus is estimated by Allard at 4500 French, or about 43,200 English units. With the luminary of two machines in focus this intensity is doubled, and would thus appear to be about 86,400 English units.

Fig. 1644 is a section, and Fig. 1645 a plan of the lantern at Cape Grisnez; here two steam engines and two Alliance magneto-electric machines are placed in a room at the base of the tower. The electric light is exhibited from a small cylindrical lantern attached to the service room as at Cape La Hêve, the old lantern and optical apparatus being retained in case of accident to the electric light. The optical instrument consists of a dioptric apparatus of the sixth order for fixed light, having a focal distance in the central plane of 150 mm. Around this are rotated vertical lenses for producing the flashes, one lens being devoted to each flash. This optical apparatus, as well as those at the La Hêve lighthouses, was manufactured by L. Sautter, Lemonnier, and Co., of Paris.

In the discussion on Douglass's paper, Admiral Collinson stated that on consulting the lights of the world, it will be found that about sixty distinctive characters are used. Babbage, in 1851, thought it would be desirable that a number should be given to each lighthouse, that symbols should be employed to represent that number, and that the lighthouse should keep continually reproducing it; other suggestions had been made. Of late years the principal one had been by Thomson, who had suggested the introduction of the dot-and-dash system, in order that, by means of the Morse code, each lighthouse might be enabled to spell its own name. Practical seamen, however, thought that something might intervene between them and the lighthouse, and that they might begin to spell the word in the middle instead of the beginning. A ship might be interposed, or the lightkeeper might, in doing something in the lantern, interpose his head. It was therefore thought better to adhere to the system already in use, by which each lighthouse proclaimed its own individuality in a simple and unmistakable manner, and to let the sailor bear the onus of making himself acquainted with the special characteristic of each light. The great increase in the number of lights, however, had of late caused some complication, when fortunately Wigham, in experimenting with gaslight, suggested the plan of cutting up long flashes into groups, by which method the power of the light would not be impaired, and the flashes could be repeated at short intervals. When it was ascertained that the system of group flashing secured an absolute equality of power in the flashes, and a more effective plan for distinctive purposes, it was at once adopted.

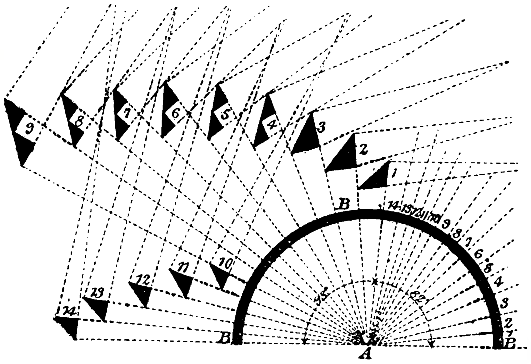
TABLE I.—SYSTEM OF DISTINCTIVE CHARACTERS OF LIGHTS.

Coast Lights.		Harbour Lights.	
Flashing.	Relative Approximate Intensity present fixed White Light, 100.	Flashing.	Relative Approximate Intensity present fixed White Light, 100.
1. White single flashing	550	1. One white and one green flash	367
2. „ double „	550	2. „ „ two green flashes	306
3. „ treble „	550	3. Two white and one green flash	407
4. „ quadruple flashing ..	550	4. One white and three green flashes	275
5. „ quintuple „ ..	550	5. Two white and two green flashes	367
6. One white and one red flash ..	393	6. Three white and one green flash	458
7. „ „ two red flashes	340	7. One white and four green flashes	257
8. Two white and one red flash ..	445	8. Two white and three „	330
9. One white and three red flashes	314	9. Three white and two „	403
10. Two white and two „	393	10. Four white and one green flash	477
11. Three white and one red flash	471	11. One green and one red flash ..	250
12. One white and four red flashes	298	12. „ „ two red flashes	271
13. Two white and three „	361	13. Two green and one red flash ..	227
14. Three white and two „	424	14. One green and three red flashes	282
15. Four white and one red flash	487	15. Two green and two „	250
16. Red single flashing	235	16. Three green and one red flash	216
17. „ double „	235	17. One green and four red flashes	289
18. „ treble „	235	18. Two green and three „	262
19. „ quadruple flashing ..	235	19. Three green and two „	236
20. „ quintuple „ ..	235	20. Four green and one red flash ..	209
Mean	393	21. Green single flashing	183
		22. „ double „	183
Occulting.		23. „ treble „	183
		24. „ quadruple flashing ..	183
21. Single occulting	100	25. „ quintuple „ ..	183
22. Double „	100	Mean	282
23. Treble „	100		
24. Quadruple „	100		
25. Quintuple „	100		

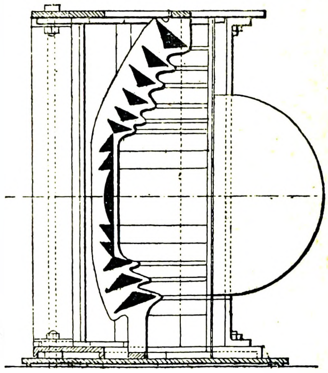
In using different colours, to keep the flashes of the same power, it was necessary to put a greater space into the red light; and thus we have now the power of raising the intensity of the red up to that of the white light. In the foregoing table it will be seen that by cutting up the beam of light into two, three, four, or five sections, and employing the red colour, which, as just stated, can be brought up to equal power with the white, no less than twenty simple distinctions available for coast illumination can be obtained, the mean power of the light thus produced being 393, as against 100 for a fixed light. By the introduction of green colour twenty-five distinctions could be made available for harbour lights, with similar advantages, namely, that every light would be of the same power and would show precisely the same distance, no matter what the weather might be. With the green colour introduced, the mean power of the light produced would be 282, as against 100 for a fixed light. In reference to this question of distinction, no doubt the electric light is well adapted for the accomplishment of the effects required. By its aid the flashes were rendered intense and forcible, and the transitions from light to darkness, and the reverse, were clearly defined.

With reference to the optical instruments employed in lighthouses, Thomas Stevenson states that the two most important are the holophotal totally reflecting prisms, by the single agency of which the rays are parallelized both in the horizontal and vertical planes; and doubly reflecting prisms, by which metallic agency was altogether dispensed with, and dioptric apparatus by glass substituted in its place. In applying these instruments to some of the optical arrangements in use for adapting lighthouse apparatus to different local requirements, the azimuthal condensing system is largely employed; the principle has been applied to the electric light, and Stevenson has combined with the condensing system the twin prisms, numbered 4, 5, 6, 7, 8, 9, Fig. 1646, a form which admits of the more easy adoption of Swan's proposal of placing prisms behind those in front, so as to cause the light coming from those behind to pass through the spaces between the front prisms. At Lamlash, where the twin prisms were first employed, the apparatus has been thus made so compact, as to reduce to a large extent the size of the light-room which would otherwise have been required, while the loss due to absorption in passing through the glass has been also materially reduced. The greatest amount of condensation Stevenson has had to carry out was at Cape Van Diemen, New Zealand, where the whole 360° was condensed uniformly over a sector of 30°, Figs. 1647, 1648.

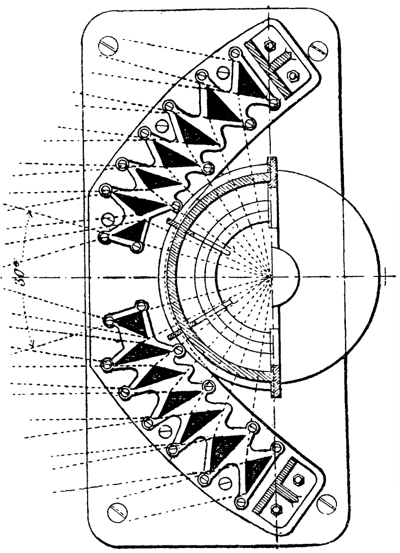
1646.



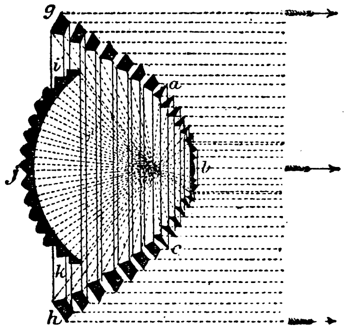
1647.



1648.



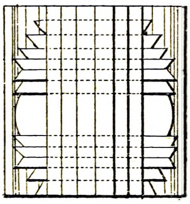
1649.



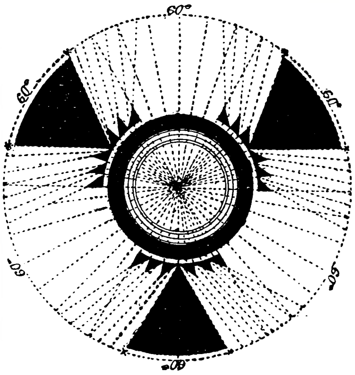
A further improvement, increasing the extent to which total reflection can be carried, are the back prisms. The Fresnel form of prisms is limited in its optical action to the critical angle, which, for most glass, restricts the angle of deviation to 90°, beyond which angle those prisms are inoperative; whereas the back prisms can, if necessary, be made to render the rays parallel up to nearly 180°. These prisms are shown in the holophote, Fig. 1649, by the letters *a*, *c*, *g*, *h*.

The application of the azimuthal condensing prisms to dioptric revolving, flashing, and intermittent lights, due to T. Stevenson, is delineated in Figs. 1650, 1651, and it consists of straight prisms revolving round a fixed light apparatus. In the arrangement Figs. 1650, 1651, these prisms intercept the light so as to produce perfect darkness over the arc they subtend, while the light which falls upon them, instead of being parallelized, is spread uniformly over the intermediate sectors of light which come from the fixed apparatus. By this mode the use of double agents is restricted to certain portions of the apparatus only. Thus the power of the light is increased, in direct proportion to the duration of the intervening periods of darkness, for the rays which are intercepted by the upright prisms are bent, so as to become auxiliary to the intervening illuminated sectors. Neglecting the loss due to absorption, the power is doubled when the periods of light and darkness are equal, trebled when the periods of darkness are twice as long as the light, and so on in proportion; while in every case the rays are spread with rigid equality over each illuminated sector. The periods may, within certain limits, be made unequal; or coloured lights may be adopted, in which the power could easily be equalized.

1650.

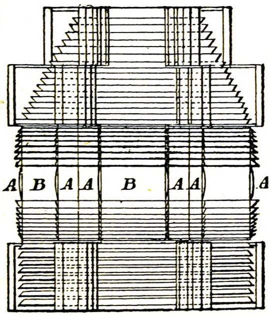


1651.

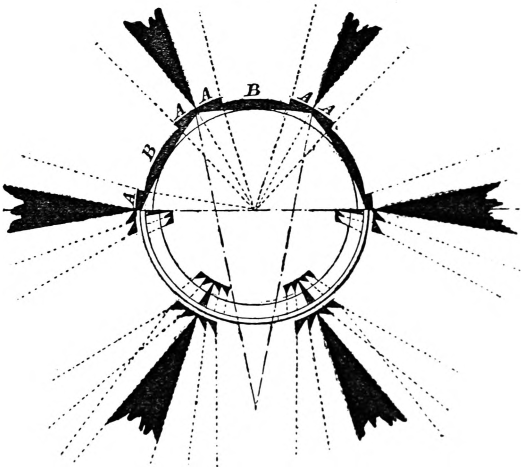


By using the principle of the differential lens, it, in this case, becomes a differential cylindric refractor, whose centre of inside curvature is ex-focal, that takes the place of the central refracting drum in Fresnel's fixed light. In the Mull of Galloway apparatus, all the parts of which revolve together, this differential refractor, marked A B in Figs. 1652, 1653, would be a meniscus in horizontal section, so as to condense 60° into 40°, which is needed to give the required characteristic of the Mull of Galloway, namely fifteen seconds dark and thirty seconds light. The vertical profile of this instrument will be the same as that of the ordinary cylindric refractor, while the upper and lower joints will be convex conoidal and concave conoidal respectively. By the compound action of this single agent the whole effect of the intermittent light will be produced, so that two agents are saved at the central refracting part of the apparatus. The straight prisms will not, therefore, extend beyond the upper and lower cupola of reflecting prisms. The difficulty of execution prevented the application of the same principle to the upper and lower prisms.

1652.



1653.



Both the differential lens and refractor are well adapted for the requirements of the electric light. In experiments made at Edinburgh, in 1868, by Stevenson, with the common plano-convex lens with the ordinary lenticular divergence, the differential lens with 2½° of artificial divergence in azimuth and ordinary vertical divergence, and a double lens having 6° of artificial divergence in azimuth and 3° in altitude, the following results were obtained with the liquid photometer;—Plano-convex lens = 1·00; differential lens = 0·90; double lens = 0·75. The result shows that the double lens is not only much inferior in power, but that the distinguishing peculiarity of the electric flash was so far lost as to assimilate it in a great degree to the oil lights. This seems to show that the highly distinctive flash of the electric light, when acted on by optical apparatus, is not so much due to a greater amount of light as to the more complete parallelism of the rays, effected by the refracting medium through which they passed.

The dioptric combinations employed in the lighthouses referred to pp. 835 to 837, were entrusted to James T. Chance; they are described in the M.I.C.E., vol. lvii., from whence the succeeding account is condensed.

In the Fresnel, or dioptric, apparatus the source of light is placed in the centre of a structure of rings, or annular segments of glass, of such generating sections that all the incident light may be condensed and directed upon the sea. This condensation may take place only in vertical axial planes; in that case the sea is uniformly illuminated in all directions in azimuth, and the apparatus is termed a fixed light. The sphere of light may, however, be divided into various portions by vertical planes through the centre; and each segment of light may be condensed both vertically and horizontally. The result is a number of separate solid beams; and, in order that they may be seen by the mariner, the apparatus must be made to rotate. This, accordingly, is called a revolving light.

The following preliminary remarks refer to fixed lights; and the term divergence is therefore used for that in a vertical plane only. When a flame is employed as the luminary in a lighthouse, it is not enough to cause the rays from any point of it to emerge in parallel directions; for the angle of divergence arising from the height of the flame must also be compressed within useful limits, in order to avoid waste of luminous power. This can be effected only by enlarging the diameter of the apparatus proportionately to the height of the flame. But even the largest apparatus now in use, though 1·84 metre in diameter, is inadequate for the increased flames introduced of late years into lighthouses.

There is manifestly great economy in employing a small instrument; and also an evident simplicity in adopting one whose radius is short enough to enable a diminutive radiant, by the vertical angle it subtends, to afford all the divergence wanted for covering the sea to the requisite distance towards land. But the carbon points of the electric light cannot yet be depended upon for immobility upwards or downwards, so that there is always a contingency of a change in the direction of the angle of emerging light, inasmuch as this moves together with the radiant itself. There is, moreover, no proper gradation in the intensity of the illumination of the sea at different distances. The light which is emitted upon the sea at a few miles from land may be as powerful as that which is directed towards the horizon, whereas the quantity of light thus lavished on the near sea ought to be added to that which is transmitted to the horizon.

With the flame a gradation of light does exist. For example, according to Allard, with a first order fixed apparatus, having a lamp of five wicks, out of the total quantity of light included in a solid angle of 6° in height, 45 per cent. is contained in the angle of only 1° in height that is bisected by the horizon direction. The Fresnel system of zones renders it easy to imitate with the electric light this effect of gradation, so as to allot to different distances on the sea whatever proportions of the total quantity of available light may be desired. But to attain this end, and to eliminate the defects which have been indicated, it was necessary to abandon, in the case of the early use of the electric light, the plan, however obviously suitable to flames, of depending upon the height of the luminary for the required vertical divergence, and to be thus free to reduce considerably the divergence due to the height of the light, so as to be able to utilize this radiant to the best advantage. This could be accomplished only by employing an optical instrument of much increased diameter.

A portion of this larger apparatus may still be allowed to parallelize the radiant light; thus the emerging beam, now greatly compressed, may be devoted to illuminate the horizon and distant sea, while special generating sections may be given to the rest of the apparatus, so as by suitable angles to distribute the illumination from the horizon towards land, to such distances and with such gradation of intensity as may be desired.

The divergence due to the luminary will, of course, always move with it, however large the apparatus may be, in case of deviation of the carbon points from their proper position; but when it is borne in mind how small an angle of divergence, generally less than 15′, covers as much as three-fourths of the sea from the horizon inwards, it is clear that no such displacement of the carbon points could cause the sea to be left in darkness, provided that a due angular margin be allowed, between the direction of the horizon, and the upper boundary of the special divergence obtained from a portion of the apparatus.

With a large instrument, moreover, luminous power may be spared for spreading light by means of particular zones over any special part of the sea. This will be exemplified in describing the South Foreland lights. Generally, the rays issuing from the electric light can be controlled by the Fresnel system of independent zones, so as to be made to illuminate any part of the sea with any required relative intensity. Such diversion, however, of any light from the horizon could not be permitted if the whole emerging light has unavoidably, as in the case of a small apparatus, a large divergence.

It would be superfluous, when such urgent reasons exist for preferring a large apparatus, to adduce other considerations of less importance which confirm the same view.

Since the construction of the apparatus here described, a great advance has been made in the electric light itself, and certain modifications have been adopted, which produce varying intensities in different directions in azimuth. These latter changes, if maintained, will have to be taken into account in designing future apparatus.

It was a matter for consideration whether two condensations, the vertical and the horizontal, could be effected without employing two optical agents. No difficulty of this kind presents itself in the case of a flame, for all that has to be done is to render each segment of the apparatus lenticular, with its principal focus in the appropriate point of the axis of the flame, and then the vertical and horizontal divergences are those corresponding to the height and breadth of the flame; or, in other words, an image of the flame itself is formed externally by each segment, as would be made evident by throwing the beam on a white screen placed in the dark at a suitable distance. But to treat the electric light in this way would not satisfy the requirements of the mariner, for the horizontal divergence would be so small, that the duration of the flash on the eye of the observer would be only momentary. If the diameter of the electric arc be taken to be 12 mm., the duration of the flash would even then be under one second, unless the intervals of darkness be too much prolonged.

To consider then, first, the annular lens; the idea which at once manifestly presents itself is so to shape its successive generating sections that they will give the required horizontal divergence. One-half, however, of the increased vertical angle, which would accompany the horizontal divergence, would be bestowed upon the sky.

A. Brebner proposed to remedy this defect to some extent by dividing the lens at the horizontal central plane, and lowering the upper half, so that the upper half of vertical divergence should be superimposed upon the lower and the total angle be thus reduced to one-half. But the two divergences, horizontal and vertical, would still be left to be connected together.

Stevenson proposed to obtain two independent divergences by adopting the plan, devised by him in 1861, of giving to the inner surface of Fresnel's annular lens two different concave curvatures, the one horizontal, the other vertical. An account of this contrivance will be found in Stevenson's treatise on 'Lighthouse Illumination.'

In 1870, when J. T. Chance was entrusted by the Trinity House with providing optical apparatus for the electric light at Souter Point, he decided to adhere to the system which had been adopted in France for revolving lights with the electric arc, and which indeed, as late as 1851, was used there to condense horizontally the light emerging from the catadioptric portions of a Fresnel apparatus. This system consists of a fixed light surrounded by a polygonal drum, each of whose sides is composed of straight vertical lenses, so shaped as to give the required horizontal divergence.

1654.

1655.

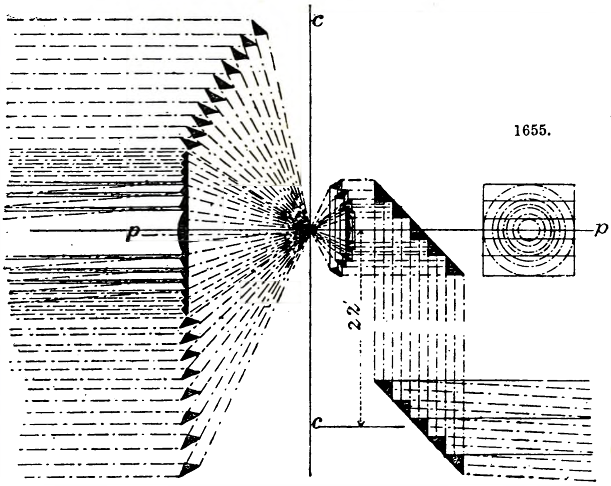
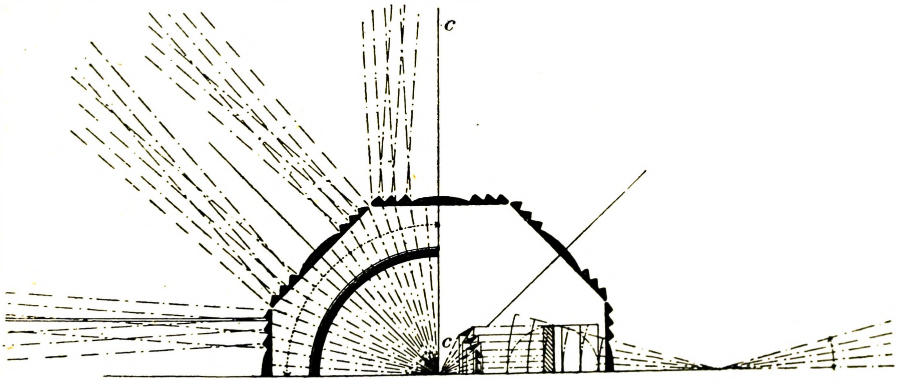


Fig. 1654 is a vertical section of the apparatus at Souter Point, and Fig. 1656 a half sectional plan through the focal plane *p p*, *c c* indicating the centre line of the light. Fig. 1655 is an elevation of the holophote and horizontal prisms. At Souter Point the light had to be visible during five seconds every half minute, thus leaving an interval of darkness of twenty-five seconds' duration. The dispositions are as follows;—The electric light is placed at the centre of a fixed apparatus of 1 m. in diameter, and embracing 180° horizontally. The refracting portion consists of a middle belt and of twelve zones, six of which are above the belt, and six similar ones below it. The whole series subtends in height an angle of 66° 42′ at the centre. There are ten upper catadioptric zones, subtending at the focus a vertical angle of 43° 20′, the lower side of this angle being inclined

1656.



to the focal plane at 35° 2′; and also eight lower catadioptric zones embracing a vertical angle at the focus of 30° 17′, its upper boundary making with the horizontal direction an angle of 35° 14′. Hence 140° in height out of 180° are acted upon by the glass portion of the apparatus, but the actual portion of the whole of the light contained between any two meridian planes intercepted by the zones of glass is 92 per cent.

The apparatus is divided, as regards vertical divergence, into two distinct sets of elements. The middle refracting belt, together with the three zones next above and the three zones next below it, are made to give a divergence of 1° above the horizon and 3° below it, in addition to that due to the dimensions of the electric arc; whereas the three highest refracting zones and the three lowest zones, together with the whole of the catadioptric cupola and all the lower catadioptric group, depend for the divergence of the rays issuing from them, upon the angles subtended at each of them by the electric arc. To the 3° of special divergence provided for the sea must be added half of the luminary divergence. If 9 mm. be taken as the height of the electric arc with one machine, the total divergence on the sea will be 3° 31′. The focal plane of the light is 150 ft. above high water, so that this angle of 3° 31′ will extend up to 772 yds. from the tower.

The angle of 1° above the horizon is allowed, in order to provide for any ex-focal displacement of the electric arc in a vertical direction; but this allowance, as it concerns the maximum intensity, is only 29′, for the semi-angle due to the size of the electric arc, taken as 9 mm., has to be deducted, inasmuch as the maximum intensity would extend over the whole angle, on the supposition only that all the light proceeded from a mere point, instead of from a radiant having magnitude. The addition of the divergence of the radiant to the special divergence given by the apparatus, causes the latter angle to open out, and therefore diminishes the luminous intensity of the expanded beam at each of its sides, in regular gradation, over an angle equal to the divergence due to the size of the radiant, one-half of which falls within the angle of special divergence.

The revolving drum consists of eight equal sides divided into three panels in height, each of which is composed of seven vertical lenses, one in the middle and three on each side of it, their height being equal to that of the fixed apparatus within, the diameter of the inscribed circle of any horizontal section being 1·40 m. The generating section of each lens is such that the light which falls upon it from any point of the luminary is spread over 7° 8′ in azimuth, the axes of the emerging beams from each of the lenses of any one of the eight sides, being perpendicular to the interior face of that side. While therefore the angle of horizontal divergence belonging to any side of the octagonal revolving drum is passing across the vision, all the seven vertical lenses appear to the eye to be simultaneously illuminated.

The diameter of the electric arc, as originally communicated to Chance, subtended an angle of only 22′; and this, added to the special divergence of 7° 8′, gave a total divergence of 7° 30′, which was expressly calculated to give 5″ of flash; but the diameter of the carbons has since been increased to 9 mm. for one electric machine, and to 12 mm. for two machines.

The sections of the lenses are so calculated as to spread the light uniformly over the angle of horizontal divergence, and, except for a small angular space on either side of this angle, arising from the additional divergence due to the diameter of the luminary, there is no waxing and waning, such as is the case when a flame is the source of light, but the full brilliancy of the flash comes almost at once upon the eye, and so continues for nearly its entire duration.

It is evident that where the flash is most intense in the centre, and becomes gradually weaker towards either boundary of the angle, the visible divergence and therefore the duration of the flash diminishes as the eye recedes. On the other hand, the maximum intensity of the flash suffers a diminution corresponding to the maintenance of a uniform intensity throughout the entire angle.

With a flame there is no choice; the increase of the intensity from a minimum to a maximum, and then the reverse gradation, are its necessary concomitants. Thus in a first order revolving light, with a five-wick lamp, according to Allard, the intensity of the middle of the flash in the middle of the focal horizontal plane is 7150 French units; but if the intensity were uniform throughout the whole angle, its mean value would be only 4700 units.

The electric light, however, can be easily made to exhibit the appearance of waxing and waning in various ways, such as by eccentring the upper and lower panels of vertical prisms, so as to produce any gradation of intensity that may be desired.

The fixed light embraces only 180° in azimuth, so that a hemisphere of rays from the luminary was available for any subsidiary purpose. Douglass proposed to condense the chief part of this light in a horizontal direction, and by means of reflectors to bend it first vertically downwards and again horizontally, and then to transmit it through a window in the tower 22 ft. below the apparatus, for the purpose of marking certain dangers in Sunderland Bay. In order to accomplish this, a segment of a holophote of 150 mm. radius is used, to condense 54·6 per cent. of the back hemisphere into a nearly cylindrical beam. This is intercepted and sent vertically downwards, by a group of five right-angled straight catadioptric prisms, upon a group placed directly below them of five similar prisms, by which it is transmitted a second time horizontally. These latter prisms, however, are curved lengthways, so as to cause the emerging rays, which otherwise would form a nearly cylindrical beam, to converge at an angle of 31° within the tower, and thus to diverge on issuing from it at the same horizontal angle; and the generating sections of these concave prisms are so shaped as to produce a dipping light, limited within the vertical angle required to cover the desired distance on the sea.

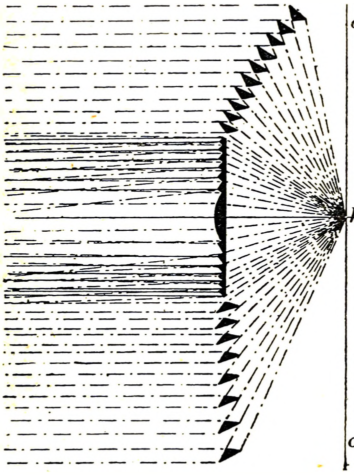
Figs. 1657 to 1662 refer to the dioptric apparatus at the South Foreland. Figs. 1657, 1661 are vertical sections, Figs. 1658, 1661, elevations of the holophotal semi-lenses, and one vertical prism, and Figs. 1659, 1662, half plans; *p* indicates the focal plane, *c*, *c*, the centre line of each light, and *h*, *h*, the horizontal axis of each holophotal semi-lens. There are two lights. The high light has its focal plane at an elevation of 372 ft. above high water, and that of the low light is at an elevation of 275 ft.

A third order fixed apparatus is used with the high light. The refracting zones, Figs. 1657 to

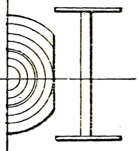
1659, are made to spread the light falling upon them from the central focus over various angles of vertical divergence, all of which commence 1° above the horizon direction, but extend to increasing angular distances below it. Thus, the belt sends its light up to 1°, the fifth and six pairs of zones above and below it to 1½°, the fourth pair to 2°, the third pair to 2½°, the second pair to 3°, and the first pair up to 5° 24½′, which corresponds to 1174 yds. from the tower.

While, therefore, each of these angles of vertical divergence includes the horizon, they follow each other in succession, reaching farther and farther, until the largest angle brings the illumination up to the required distance from the lighthouse itself. It will be observed that the lenses above and below the middle belt act together in pairs, the object being to provide for the contingency of any part of the light from either one of them being intercepted by a bar of the lantern. The light incident on the upper and lower series of catadioptric prisms is parallelized, and directed towards the horizon.

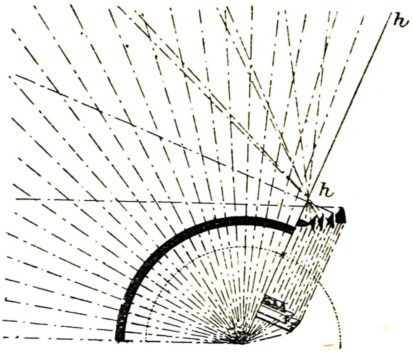
1657.



1658.

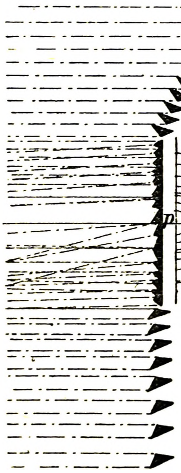


1659.

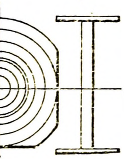


The fixed third order instrument illumines 226° in azimuth, so as to leave an arc of 134° of spare light on the landward side, which is employed to strengthen the front or seaward arc in the high light, by means of the following optical arrangements;—A small space in the middle of the landward arc is required for introducing or removing the electric lamp, but nearly all the remaining available light is used to intensify the illumination of the front arc. For this purpose a holophotal semi-lens, in a rectangular panel, is fixed on each side of the rearward boundary of the main instrument, so as to have its focus at the electric arc. The focal length of each lens is 187½ mm., and its axis lies in the horizontal focal plane, and is coincident with the landward boundary of the front arc. On each side of the apparatus is also fixed a series of five vertical prisms of the usual kind of glass, 533 mm. in height, of which one is refracting, having its flat side perpendicular to the axis of the lens, three are catadioptric of the ordinary section adopted by Fresnel, and the fifth is a back prism of the form suggested by Stevenson, as admitting of the deflection of light considerably beyond 90°. This is referred to in Fig. 1649.

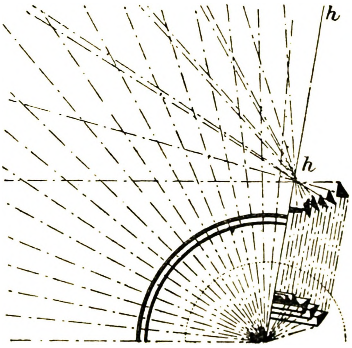
1660.



1661.



1662.



The form used by Fresnel was limited by the restriction of making the two refracting sides of the generating section coincident with the paths of the two extreme incident rays, so as to secure the minimum thickness of glass. No one, however, can doubt that Fresnel would in the first instance express his formulæ in the most general terms, but in the apparatus which he invented any deflection beyond 90° by totally-reflecting prisms was not required. This series of vertical prisms intercepts the beam which emerges from the lens, and deflects and spreads it uniformly over the one half of the illuminated arc. The various sections, however, receive different quantities of light, so that, in order to render the emerging light of uniform intensity, the sections must be so calculated as to have angles of emergence independent of each other. For this purpose the generating section of each of these vertical prisms has its own distinct focus.

In the low light, Figs. 1660 to 1662, the illumination of the sea was to be brought even nearer to the lighthouse than in the previous one, namely, up to 304 yds. from it. To effect this, the middle belt is divided into four zones, two immediately above and two immediately below the focal horizontal plane, and of such sections respectively that the two upper zones spread out their light from the direction of 3° 41′ below the horizon line up to that of 17° 23′, which corresponds with the spot of 304 yds. from the tower; and the two lower zones spread their light from the direction of 5° 11 below the horizon line, also up to that of 17° 23′. The refracting zones above and below are made to act the same as in the high light, and all the catadioptric prisms likewise parallelize the light incident upon them, and transmit it in the direction of the horizon. In the low light the main apparatus illuminates 199° in azimuth, so that the arc of spare light is 161°. The available landward light is utilized, as in the manner just described, by a semi-lens and vertical distributing prisms, placed on each side of the back of the main instrument. These vertical prisms are six in number, and consist of one refractor, four Fresnel prisms, and one special prism for deflecting beyond about 90°.

At the Lizard there are two lights, exactly alike in construction; and in each of them the whole of the apparatus, except the five refracting zones below the middle belt, is calculated to parallelize the rays from the luminary. These five zones are diverging ones. The first, namely, the one immediately below the belt, together with the fourth and fifth, co-operate as if only one zone, in ranging from the horizon to 9° 30′ below it. The second and third co-operate in the same manner, and together range from the horizon to 9° 30′ below it.

TABLE II.—CONDENSING POWER. FOR THE HORIZON AND DISTANT SEA.

	P.	D.	Proportion emerging from Apparatus.	Proportion emerging from Lantern.	——	Emerging from Lantern.
Souter Point, Revolving.						
Catadioptric zones	44·226	..	·71	·84	26·376	
Refracting. Belt and three zones above and below 4° divergence	..	12·146	·87	·84	8·876	
Refracting. Three highest and three lowest zones	12·02	..	·87	·84	8·784	
					44·036 ×	
Vertical prisms of the revolving drum	..	6·17	·87	..	5·368	236·38
South Foreland, High Fixed.						
Catadioptric zones	44·226	..	·71	·85	26·691	
Refracting belt and zones	..	22·6	·87	·85	16·705	
Auxiliary wings	13·235	..	·64	·80	6·776	
						50·17
South Foreland, Low Fixed.						
Catadioptric zones	44·226	..	·71	·85	26·691	
Refracting zones, except belt	..	10·9	·87	·85	8·061	
Auxiliary wings	16·901	..	·64	·80	8·653	
						43·40
Two Lizard Lights, Fixed.						
Catadioptric zones	44·226	..	·71	·85	26·691	
Refracting. Belt and upper zones	32·2	..	·87	·85	23·812	
Refracting. Lower zones dipping to 9° 30′	..	2·1	·87	·85	1·553	
Auxiliary wings	12·463	..	·64	·80	6·383	
						58·44

TABLE III.—CONDENSING POWER. FOR THE NEAR SEA.

	Condensation.	Angular Distance below the Horizon Direction.		Linear Distance from Tower.
		°	′	
South Foreland, High Light, Fixed. Elevation, 375 ft.	23·481	1	0	2·7256 naut. miles.
	15·038	1½	0	1·9604 „
	12·421	2	0	1·5319 „
	4·089	2½	0	1·2576 „
	2·699	3	0	1·0667 „
	1·242	5	24½	1174 yards.
South Foreland, Low Light, Fixed. Elevation, 290 ft.	16·714	1½	0	1·5505 naut. miles.
	15·441	2	0	1·2070 „
	4·089	2½	0	2003 yards.
	2·699	3	0	1696 „
	1·871	5	24½	974 „
	1·338	17	23½	304 „
Two Lizard Lights, Fixed. Elevation, 227 ft.	7·936	1	50	1·0323 naut. miles.
	1·553	9	30	441 yards.
Souter Point Light, Revolving. Elevation, 150 ft.	47·646	3	0	855 „

The South Foreland lights were entirely made expressly for the purpose, but those at the Lizard had to be so arranged as to utilize the chief portion of a third order fixed light, which had been previously constructed for the Trinity House, and the optical arrangements had to be accommodated to this restriction.

An arc of 235° in azimuth is illuminated in each of the two lights, so that in each case the auxiliary apparatus has to produce a maximum deflection of 120°. This consists, as in the South Foreland lights, of a holophotal segment of 187½ mm. radius, and a series of vertical prisms on each side, comprising one refractor, two Fresnel prisms of the usual glass, one Fresnel prism of dense flint, and one back prism of dense flint. The small holophotal segments are movable round vertical axes to allow of manipulating the lamp. The apparatus at the two Lizard lights was designed by Hopkinson.

It will have been observed that in all the lights which have been described, the chief part of the important duty of providing the horizon and distant sea with the most intense illumination, has been made to devolve on the catadioptric zones, and on the refracting ones which are farthest removed from the horizontal focal plane. The directions in any vertical axial plane of the electric rays of chief intensity seem to justify this arrangement, but it is also worth noticing, that the angular effect of any ex-focal deviation of the carbon points, diminishes in proportion as the angle increases at which the direction of the light is inclined to the horizontal line.

The angle of vertical divergence belonging to the auxiliary apparatus of the South Foreland and Lizard lights, is that only which is caused by the size of the electric radiant. If its height be taken as 12 mm. this angle is 3° 40′, and the illumination obtained from the landward arcs is valuable, not only in strengthening the light emitted from the front arcs, but also in combining this larger divergence of the luminary with the smaller similar divergence from the main instrument.

Tables II. and III. of condensing power are calculated for a diameter of the illuminant of 12 mm. The column P refers to those portions of the apparatus which parallelize the incident light, and the column D to those which give it divergence.

The column P in Table II. is calculated on the supposition that the diameter of the luminary is 12 mm., and that the intensity is the same in all directions in the vertical plane, the mean distance for the catadioptric cupola being 687 mm., and that for the lower catadioptric cupola being 759 mm.

For any other diameter of the luminary, or for the alterations of the mean distances of the upper and lower catadioptric groups respectively, consequent on a variation of intensity of light in the vertical plane, the above data will render easy the requisite changes in the figures which denote the condensing powers of the parallelizing portions of the apparatus.

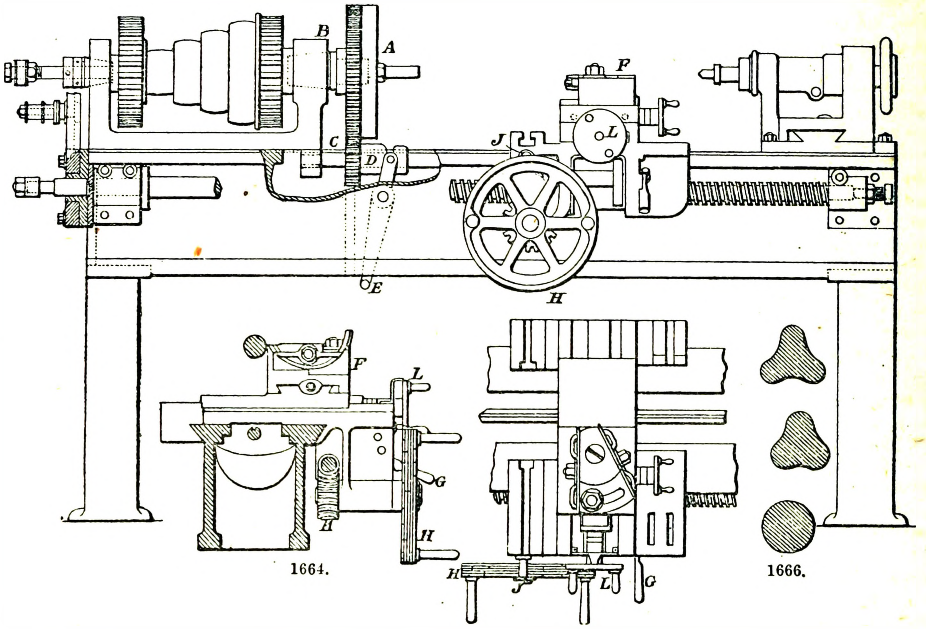
MACHINE TOOLS.

The progress in constructive engineering is always closely connected with the means of effecting improved work, and of these, machine tools form a most important feature. Although few radical changes have been made of late years, yet there have been many improvements in points of detail, and many of these will be found illustrated in this article.

Lathes.—A lathe designed by W. Silver Hall, of Nuneaton, presents several special points of interest. Its general arrangement, Fig. 1663, is that of a screw-cutting lathe with centres 7 in. above the bed, which is 11 in. deep and 13 in. wide across the top. The leading screw is placed in front of the bed, is 2 in. in diameter, and has two threads to the inch. The form of thread adopted is similar in cross-section to the tooth of a spur wheel, thus affording ample wearing surface, while it is more easily engaged and disengaged than is the case with a thread of square section. There is nothing special about the driving headstock, except that the face-plate A has cast on its back a spur wheel B, gearing in the proportion of 3 to 1, into the pinion C on the shaft D, which extends the whole length of the lathe to the following headstock. C can be slid in or out of gear by the clutch fork and lever E. A mark stamped on C, corresponding with three marked positions on the face-plate, Fig. 1663, ensures that they shall always be placed in gear in a certain definite relation to each other, and this is a matter of importance.

The saddle and slide rest are shown in Figs. 1664, and 1665. The cross slide has a very long bearing, and the wearing surfaces and screw are well protected from dirt and shavings, as is also the leading screw. The cutting tool for screw cutting is of peculiar form, being part of a steel ring carefully turned up to shape, and then cut asunder and hardened. It will be seen that it only requires to be ground straight across its end when requiring to be sharpened, and that the correct angle of thread is constantly preserved. Two of these tools, each clamped by a single nut and crossbar, are fixed in a V-shaped block F, forming the tool holder, which is pivoted on the top of the rest, and is capable of swivelling through an angle of 27½°. In the position Figs. 1663 to 1665, the right-hand, or screw-cutting tool, is in contact with the work to be chased, while that on the left hand is just clear. In the other position of the tool-holder, the flat edge of the left-hand tool is brought up, as would be required to top off the threads of a taper tap. The tools being adjusted just level with the top of the rest are always at the right height for their work, and another feature in this tool-holder, is that the correct rake of the tool is always given. Moreover, by adjusting the graduated handwheel L to any given position, the same distance of the tool point from the centre, and consequently the same diameter of work, is always ensured. For cutting a left-handed thread the tools must be turned end for end, a second tool-holder properly grooved to fit them in this new position being substituted, while for ordinary work a block with studs and crossbars, precisely like the top of an ordinary slide rest, can be put on instead of the swivelling tool-holder, in a few moments.

1663.



1664.

1666.

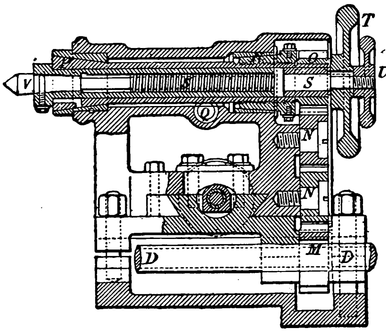
1665.

The leading screw is clamped or released by the handle G, which is very conveniently situated. The clamp nut has a long bearing and clasps both sides of the screw. For bringing back the saddle to its first position, after taking a cut the length of the screw, the handwheel H and wormwheel K, which has twenty-four teeth, are employed, the wormwheel and leading screw acting as rack and pinion, and as the wormwheel is of gun-metal and the screw has a very large wearing surface, this may be done without any injury to the screw. This wormwheel and handwheel also perform another important function. When the screw is not clamped, and the saddle is stationary on the bed-plate, the handwheel, which is graduated with twenty-four divisions, corresponding with the teeth on the wormwheel, will be seen slowly to revolve, bringing each division in turn opposite to the index J, Figs. 1663 and 1665. In these positions only can the leading screw be clamped, so by watching them the workman knows at once when to raise the handle G, without grinding the clamp nut over the surface of the screw until it will drop into position. Again, it is well known that to cut certain pitches, for example, eleven threads to the inch, it is necessary to clamp the screw as every second revolution, and if it is clamped at an intermediate revolution the thread will be split. The usual method of doing this is by watching for the coincidence of a chalk mark on the face-plate with another on the leading screw, but in the lathe in question this is provided for by a second graduated circle on the handwheel H, having only twelve divisions. There are also other circles divided into eight, six, and four parts, but these are very seldom required. By winding the screw L of the cross slide, back to its fullest extent, the slide rest can be slid off entirely, leaving the saddle, which is provided with suitable slots and bolt holes, clear for boring small cylinders, pedestals, or for other general or special work.

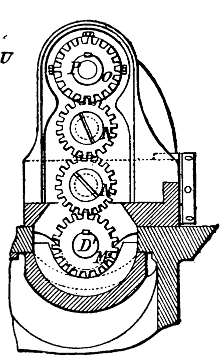
Many attempts have been made to contrive a satisfactory method for giving the relief, or backing-off, required in screw taps during the operation of chasing, so that they shall not require finishing by hand-filing, which after all can only relieve the tops of the threads, leaving the full bearing surface at the bottoms and sides. As the required relief is very slight, and demands to be accurately proportioned, these attempts have usually failed, owing to the difficulty of adjustment in the first instance, and of maintenance free from looseness and backlash afterwards. This is effected in Hall's lathe by the peculiar following or poppet headstock, Fig. 1663, and in detail to a larger scale Figs. 1667, 1668.

The shaft D, which is driven by the pinion C off the face-plate wheel B, and which makes three revolutions for every one of the lathe mandrel, imparts a similar triple revolution through the pinion M and the idlers N N to the pinion O, which is keyed on the tubular mandrel P. This mandrel revolves in adjustable conical bearings in the following headstock, but can be clamped when not required for use by a screw wedge at Q, much as in an ordinary headstock, and contains the ram R, which is propelled and withdrawn by the screw S and handwheel T, and clamped by the wheel-nut U. The nose of this ram is bored eccentrically, $\frac{1}{16}$ in. out of the centre, to receive the cone centre V. The mandrel P is caused to revolve, carrying with it R, S, T, U, and V, and a turning tool being applied to the latter it is turned up, of course truly concentric with P, and its position carefully marked O, Fig. 1670. If now it is turned half round in its seat the point will be $\frac{1}{8}$ in. out of centre, and when revolving with the mandrel P will describe a circle $\frac{1}{4}$ in. in diameter, and its adjustment for any less eccentricity may be made with very great delicacy, being measured on a graduated circle 3 in. in circumference.

1667.



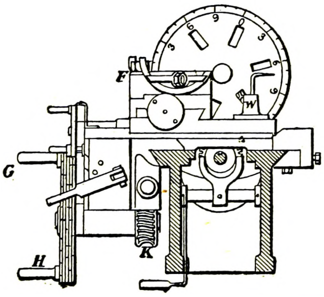
1668.



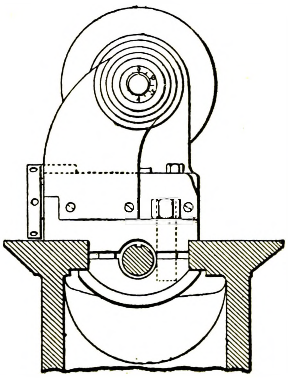
A rod or other article turned between centres will, consequently, approach to or recede from the cutting tool three times in each revolution, and at the following headstock end will receive the form of the upper diagram, Fig. 1666. This eccentricity will decrease towards the driving headstock, as in the centre diagram, approaching nearer and nearer to the true circle. A tap chased on this principle will consequently have plenty of clearance, or relief, at the commencement, while the final cut is made by that portion of the tap which is nearly circular, and a very truly tapped nut is the result.

By a curious but not difficult calculation, the mark on the face-plate corresponding with the fullest side of the tap, which varies with the degree of eccentricity adopted, which we will suppose to be seven, as shown in Fig. 1669, is found, and by bringing this number, which is repeated three times on the face-plate, opposite the point of the scriber W, which is set to the height of the lathe centre, three lines may be scribed on the shank of the tap before removing it from the lathe, giving the exact position of the cutting edges.

1669.



1670.



As the variation of radius from the true axis is alternately in excess of, and less than, the normal radius, and as it is necessary that the point of the tap should enter the same sized hole as if it were truly circular, it is necessary to set the following headstock as if for taper turning, for which purpose it is fitted with a cross slide and screw with graduated handwheel. This adjustment being very slight, does not interfere with the gearing of the pinion M and first idler N, Figs. 1667, 1668, which at the commencement are set rather deep in gear.

By adopting a double instead of a treble ratio in the eccentric gear, an elliptic figure is obtained, and in this manner, and by varying the distance between the front and back centres, the blocks or moulds can be obtained in endless variety, and of any shape.

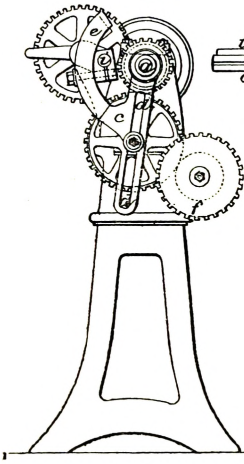
Figs. 1671 to 1673 are of a screw-cutting and turning-lathe, constructed by Ferris and Miles, of Philadelphia. It has been designed to afford a quick and convenient method of cutting screws of different pitches, and of changing from turning to screw-cutting, or the reverse.

The cone spindle *a* extends beyond the end of the lathe, and carries upon it two sliding pinions *b b* of different diameters, upon whose boss plays a double-slotted swing-arm *c*. This arm may carry by means of the straight slot *d* one or more intermediate wheels, which gear with either of the sliding pinions *b b*, and can be swung into gear with any wheel of the cone of gears *f* on the lead screw of the lathe. Also by means of the curved part with its slot *e*, the swing-arm may be fastened by its split-clamp *g* and pinch-bolt *h*, at any point of the index stud *i*.

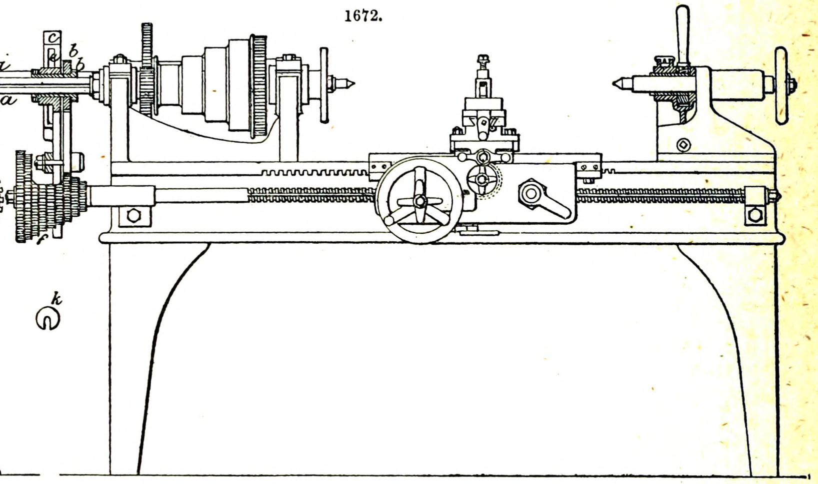
The wheels of the cone *f*, are so calculated with reference to the sliding pinions upon the spindle, that sixteen or more different screw threads of the American standard may be cut by them, say from 1 or 2 an inch pitch up to 14 an inch. These figures are laid off and stamped as an index upon the index stud *i*.

Practically, therefore, the operator has only to set the split-clamp *g*, by its pinch-bolt *h*, at any desired figure of the index. The intermediate wheel will then gear with the proper wheel upon the lead screw to cut the pitch indicated by the index figure. The upper line *p* of figures in Fig. 1673 shows the number in pinion, and the lower line *s* the number in spur.

1671.



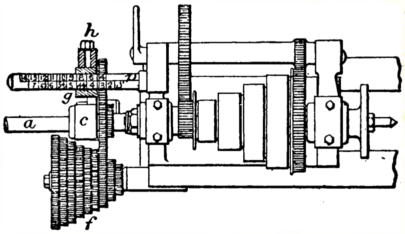
1672.



Of the two lines of figures of the index, the one marked in spur is derived from the large sliding pinion *b*, the other line marked in pinion from the smaller. The change from one to the other is made instantly, by slightly slacking the screw stud, which clamps the intermediate wheel in the straight slot *d* of the swing-arm *c*, and changing the split-washer *k* from the inside of the arm to the outside, or the reverse, the intermediate wheel being moved just one gear face, as the split-washer *g* is of just that thickness.

The thread upon the lead screw is reserved for screw-cutting only, but by means of a keyway traversing its whole length, the screw is also made to serve as a driving shaft for a train of gears in the carriage, from which is derived the cross feed motion, and also, by means of the rack upon the bed, the longitudinal traverses for turning and surfacing. These are applied and released by single motions of convenient handles. It is to be observed that the index gives sixteen or more changes of traverse by the rack gearing for turning, and surfacing, and cross reversing, in addition to the sixteen or more changes by the lead screw for screw-cutting. Therefore the operator has at his instant command a variation of thirty-two or more traverses, comprising all the screw threads in general use.

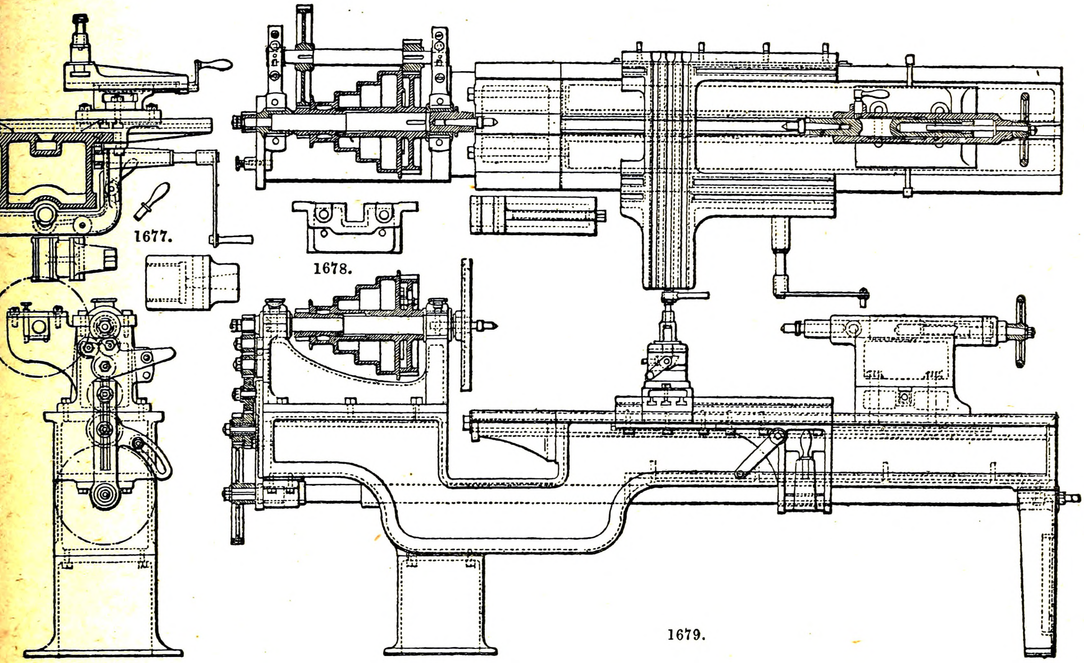
1673.



The sliding head spindle is fitted with a split conical bushing. This can be drawn into a conical seat by a nut and handle when it is wished to clamp the spindle which, by this means, is centred and held truly in line.

The lathe by Richards and Atkinson, of Manchester, Figs. 1674 to 1679, has some features differing from ordinary practice. It is intended especially for performing repair work in wood-working and other factories, and is reduced to the most simple form, so as to cheapen its first cost, and present no complication which might hinder successful use in the hands of those not well skilled. The feeding and chasing screw are placed centrally under the frame, out of the way, and well protected from chips and dirt. The distance of the feed screw from the spindles is the same as though it were placed at the side of the frame, and the nut being under the centre of the saddle, the force of the screw falls equally on each side. The nut is engaged and disengaged by a pivoted bar, Figs. 1675, 1679. The cone pulleys are respectively 12 in., $9\frac{1}{2}$ in., 7 in., and 6 in. diameter, with a width of $2\frac{5}{8}$ in. on the face. The saddle is connected at the rear end, and considerably strengthened by a strong frame surrounding the main frame, Fig. 1674; the latter frame is mounted on a strong box leg, 12 inches square, placed nearly under the gap, instead of at the end of the frame in the usual manner. The tool block is mounted on a swing plate, and can be moved to any point on the saddle, which is made with a plain flat top to accommodate boring, milling, or drilling appliances. The sliding head is arranged with a lateral adjustment for turning tapering pieces, and can be set 2 inches from the centre line. The gap piece is fitted at one end only, flat against the frame, and kept in place with accurately fitted dowel pins. The change wheels are so arranged that but a single one is changed in cutting screws from four to twenty threads to an inch. Fig. 1678 is an end view of the gap piece, and Fig. 1677 is a chuck to hold drilling tools.

Fig. 1680 is a double lathe for turning the tires of railway wheels, or executing any similar work. Two separate lathes are carried on one base-plate, thus effecting a saving of space, and rendering the machine compact and self-contained; one man can attend to both lathes, as while one side of the lathe is working he can be engaged in fixing the work on the other side, or both sides can be working together. Both the rests are fitted with two compound tool-holders, each worked by separate screws, so that they can be adjusted quite independently of each other, thus allowing two cuts to be taken on the work at the same time. The lathes are made self-acting by the ordinary overhead gear. The total weight is about 20 tons, and it is arranged to turn up to 6 ft. diameter. The driving cones have each four speeds, the largest being 27 in. diameter, and the smallest 15 in. diameter, and arranged to take a strap 4 in. wide. It is treble-geared, thus giving a great amount of driving power. The spindle wheels are 2 ft. 6 in. diameter by 5 in. wide, and the face-plate is 5 ft. 6 in. diameter; all this gearing is $1\frac{5}{8}$ in. pitch. The journals in spindles are $6\frac{1}{2}$ in. diameter by 11 in. long, and made of Bessemer steel. The bushes are of the best gun-metal. The saddles for the compound rests are 7 ft. long, the screws in them are $1\frac{3}{4}$ in. diameter, and cut with a double thread to $\frac{1}{2}$ in. pitch. The compound screws are $1\frac{3}{8}$ in. diameter. The screws for adjusting the saddles are $2\frac{1}{2}$ inch diameter, and cut two threads an inch. The total length of base-plate is 18 ft. wide, and 6 in. deep.



1674.

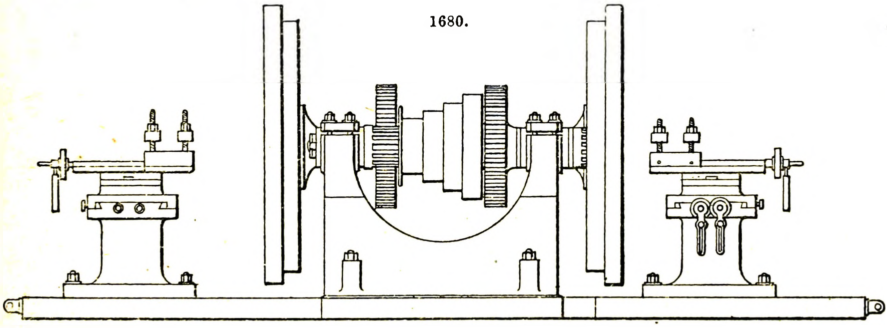
1675.

1677.

1678.

1679.

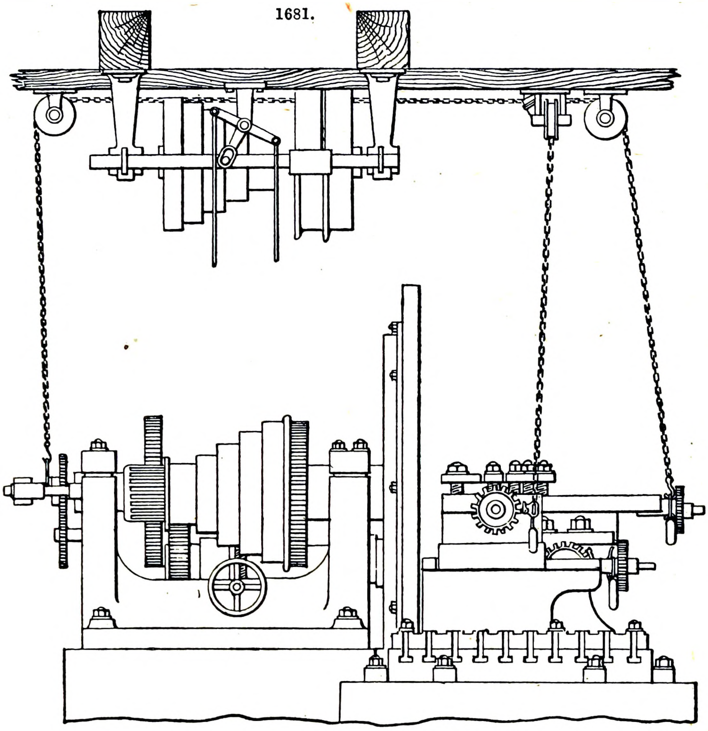
1676.



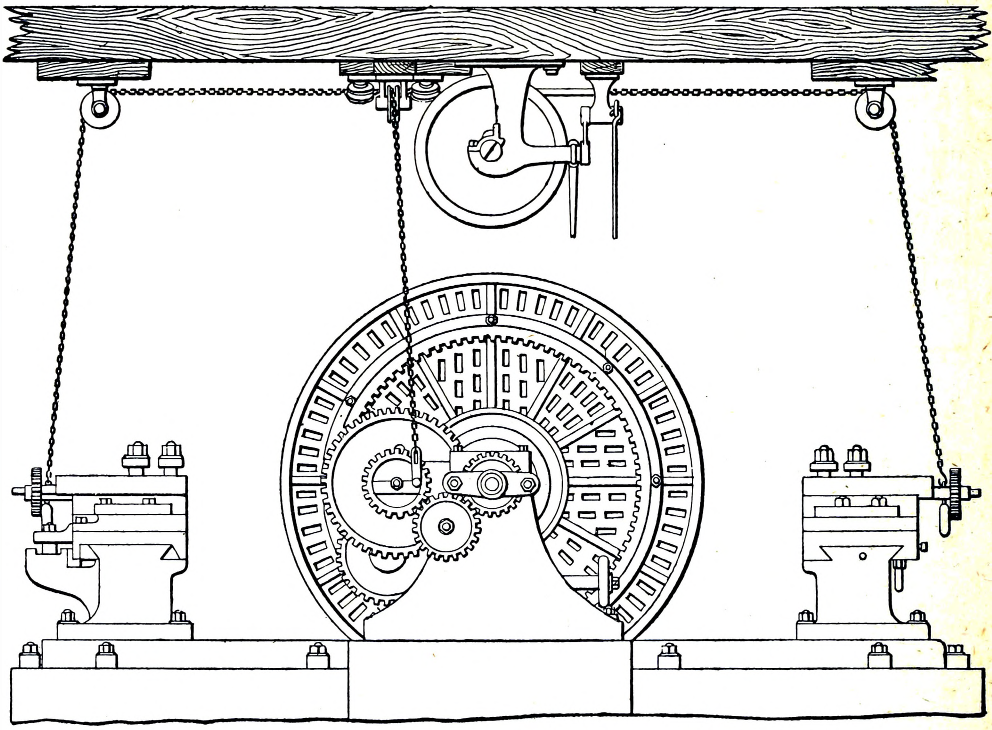
1680.

The facing-lathe, Figs. 1681 to 1683, by H. Hind and Son, of Nottingham, is a special tool designed to facilitate the turning, boring, and facing of fly-wheels, strap pulleys, and the like, which may run up to 12 ft. in diameter, and 18 in. in breadth. It consists of a massive headstock carrying a strong face-plate 8 ft. in diameter, bolted on a wrought-iron spindle 10 in. in diameter at the large bearing. The lathe is single, double, and treble-geared; the ordinary cone speeds are 5 in. broad, the large speed 2 ft. 8 in. in diameter on the spindle, and back gearing on an eccentric shaft; and has a third shaft and wheels running in an eccentric socket at the back of the headstock, on the end of which the pinion is keyed for gearing into the internal wheel bolted upon the back of the face-plate, this socket being thrown into gear with the back socket and face-plate wheel, by the worm and wormwheel moved by the handwheel in front of the headstock. There are three tool rests, each fitted with compound slides and swivel motion. The front rest is arranged with a broad holder for two tools, which will turn down the sides of a wheel rim, or the edges of drums,

1681.



1682.

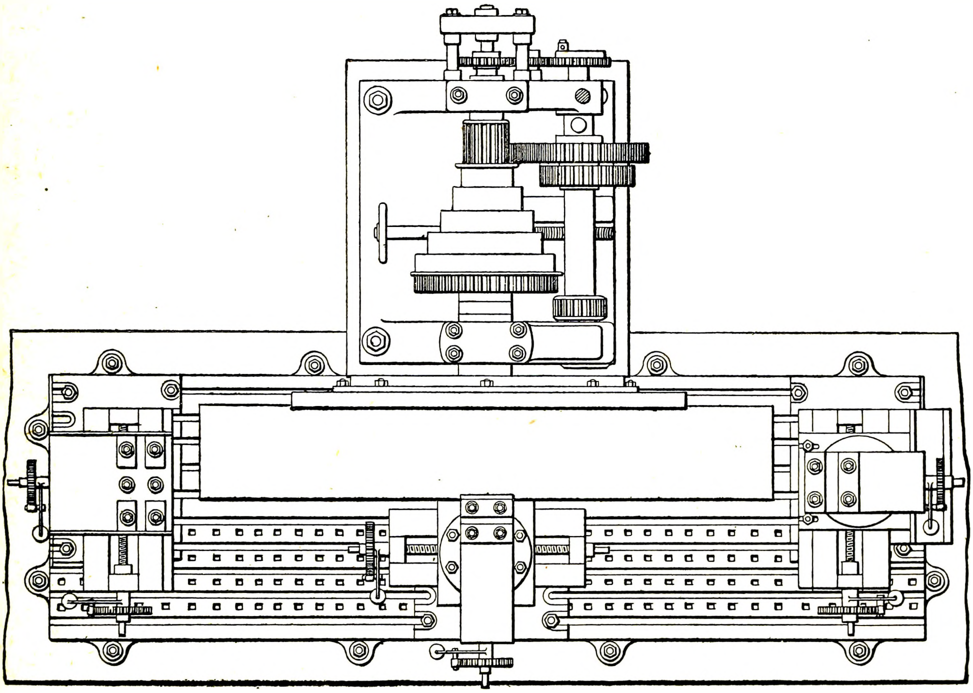


at the one operation, whilst at the back, or opposite side of the wheel more properly, the inverted tool and rest are placed for turning the faces of the fly-wheels or drums. This last rest is fitted with an additional slide moved by a steel runner working in a bracket, so that when the feed screw is traversing the tool across the face of the wheel the template moves the slides and the tool to its own curve, thereby turning the curve or rounding of wheel at one cut.

The centre rest is for boring and facing the bosses of wheels, and is fitted as the other, with compound slides and swivel motion for facing and turning the boss, and for boring; one end of the cutter bar is held in the tool-holder, and the other end of the slide is steadied in a hole 3 in. in diameter and 18 in. in depth, bored in the spindle, by which means a boss 18 in. deep can be bored if required. The whole of the rests can be worked together or separately; they are mounted on a strong foundation 17 ft. 6 in. in length, and are readily adjustable in any direction. They are worked by a chain moving a weighted lever and catch, acting on the feed wheels in any position, the chain being worked from a disc wheel on the back shaft, and driven from the main spindle end. The weight of this lathe complete is 18 tons 15 cwt.

To avoid imperfection in the running spindles of lathes, or any lateral movement which might exist in the running bearings, there have been many attempts to construct lathes with still centres at both ends for the more accurate kinds of work. Such an arrangement would produce a true cylindrical rotation, but must at the same time involve mechanical complication to outweigh the object gained. It has besides been proved by practice that good fitting and good material for the bearings and spindles of lathes will ensure all the accuracy which ordinary work demands.

1683.



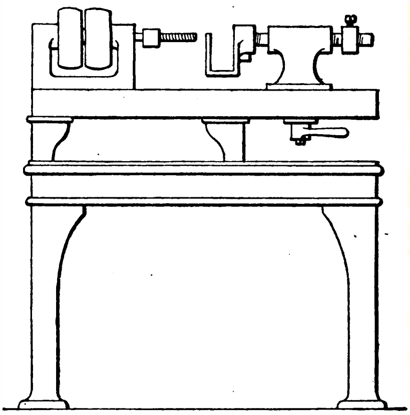
The cutting point in both turning and boring on a slide lathe is at the side of a piece, or nearly level with the lathe centres, and any movement of a carriage horizontally across the lathe affects the motion of the tool and the shape of the piece acted upon, directly to the extent of such deviation, so that parallel turning and boring depend mainly upon avoiding any cross movement or side play of a carriage. This, in both theory and practice, constitutes the greatest difference between flat top and track shears; the first is arranged especially to resist deviation in a vertical plane, which is of secondary importance, except in boring with a bar; the second is arranged to resist horizontal deviation, which in nine-tenths of the work done on lathes becomes an exact measure of the inaccuracy of the work performed.

A true movement of carriages is dependent upon the amount or wearing power of their bearing surface, how this surface is disposed in reference to the strain to be resisted, and the conditions under which the sliding surfaces move; that is, how kept in contact. The cutting strain which is to be mainly considered, falls usually at an angle of 30° to 40° downward toward the front from the centre of the lathe. To resist such strain a flat top shear presents no surface at right angles to the strain; the bearings are all oblique, and not only this, but all horizontal strain falls on one side of the shear only; for this reason flat top shears have to be made much heavier than would be required if the sum of their cross-section could be employed to resist transverse strain. This difficulty can, however, be mainly obviated by numerous cross-girts, which will be found in most lathe frames having flat tops.

A carriage moving on angular ways always moves steadily and easily, without play in any direction until lifted from its bearing, which rarely happens, and its lifting is easily opposed by adjustable gibs. A carriage on a flat shear is apt to have play in a horizontal direction because of the freedom which must exist to secure easy movement. In the case of tracks, it may also be mentioned that the weight of a carriage acts as a constant force to hold it steady, while with a flat shear the weight of a carriage is in a sense opposed to the ways, and has no useful effect in steadying or guiding. The rigidity and steadiness of tool movement is notoriously in favour of triangular tracks, so much so that nearly all American machine tool-makers construct lathes in this manner, although it adds no inconsiderable cost in fitting.

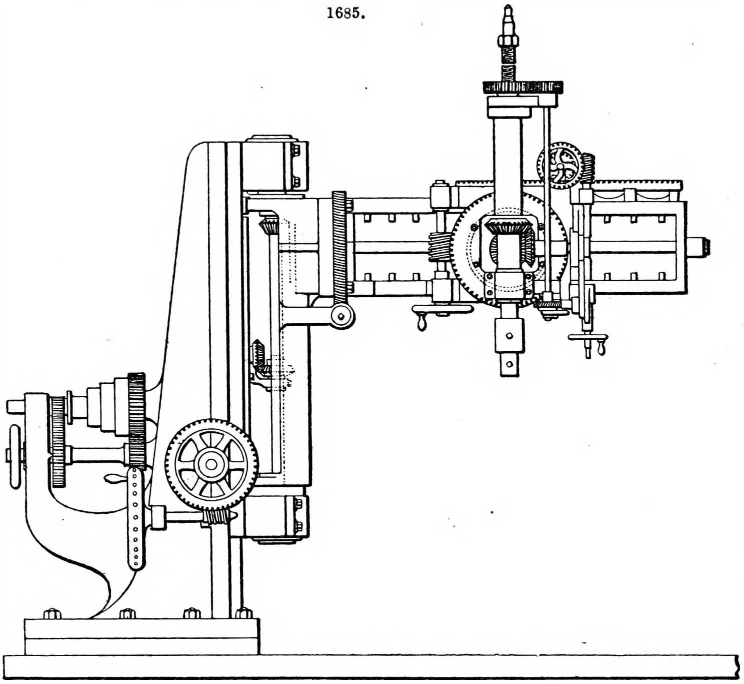
Tapping, which is the converse of screwing, is usually done by substituting a tap for the dies in a screwing machine; but where the hole is small, or does not pass through the work, there are objections to this plan. There is an ingenious form of tapping machine used by gunmakers and sewing-machine manufacturers for that kind of work. One of these machines is shown in **Fig. 1684.** The tap is clamped in a chuck on the end of a spindle, which runs in bearings in a small headstock, and has a certain amount of end movement allowed it; two pulleys run loose, in opposite directions, on the spindle, and the one at the front of the headstock revolves faster than the other. The work to be tapped is placed in a small rest, or holder, at the end of a bar that slides through a loose headstock. When the hole is to be bored, the work is pressed slightly against the end of the tap; this moves the spindle endways, and causes a lug to come in contact with the back pulley, which makes the tap revolve in the proper direction for cutting. The action of the tap draws the work forward until an adjustable collar on the bar prevents the holder moving any further; the continued action of the tap then draws itself forward in the work, and moves the lug out of gear with the back pulley, and the tap ceases to revolve. To withdraw the tap, the work is pressed gently in the opposite direction, when the lug on the spindle comes in contact with the front pulley and the tap is run quickly out.

1684.



Drilling and Boring Machines.—Fig. 1685 is a radial drilling machine by Gregson, Brown, and Son. The arm is capable of being worked round at any angle, the slide holding the spindle can also be worked at an angle by worm and wheel The whole tool is very massive and strong for the work it has to perform. The spindle is 3 in. diameter, and long enough to drill a hole 20 in. deep, and there is sufficient range of velocity in the speed pulleys and gearing to obtain the right speed to drill from the smallest size up to a 15-in. cylinder. The

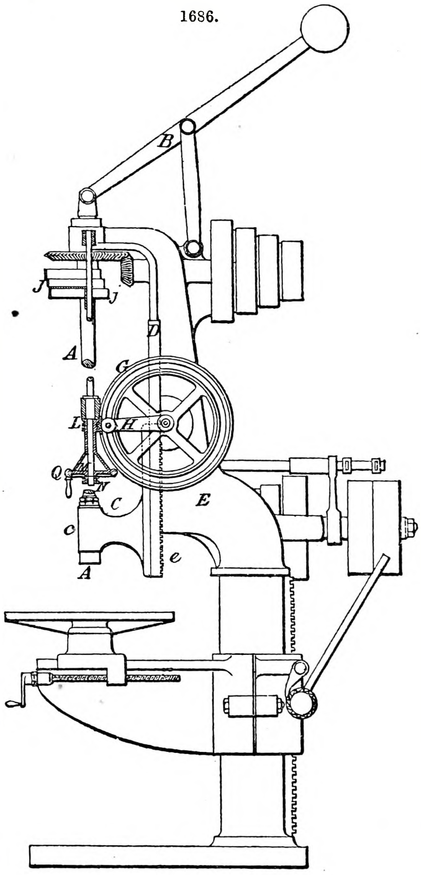
1685.



driving apparatus is provided with two sets of pulleys for fast and slow speeds. The arm is 7 ft. long from the centre of the upright shaft, and the slide is moved backwards and forwards by a rack and pinion fixed on the top of the arm, and worked by a very simple contrivance. The tool can be converted into a slot drill if required. The upright standard is firmly fixed to a planed base-plate, which is 11 ft. long by 4 ft. wide, and 6 in. deep. When the jib is worked to the top it will take in 5 ft. 6 in. from the top of the base-plate to the under side of the spindle nose, or 6 ft. to the under side of jib. The jib can be lowered 20 in. to within 3 ft. 10 in. of base-plate. It is worked up or down by a worm and wheel, and two sets of racks and steel pinions.

Fig. 1686 is of an upright drilling machine by Ferris and Miles, of Philadelphia. The drill spindle A is counterbalanced by a weighted lever B attached directly to its upper extremity, this lever holding it up securely against a fast collar on its lower end, and thus preventing the breakage of drills by any lost motion. The spindle receives its rotary motion by bevel gear, having the ratio of 3 to 1, placed near the top of the machine, the spur with its face downwards to prevent dirt lodging in the teeth. The lower end of the spindle A is firmly supported in a bearing *c* of a long carriage or saddle C, which is gibbed to the guides D of the frame E, and traverses thereon a distance of 17 in. exactly in the manner of a lathe carriage upon its bed.

1686.

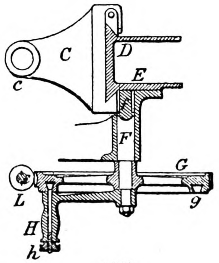


The carriage C, Fig. 1687, has a rack *e* cut upon it, into which gears the pinion *f*, whose shaft F has a crank handle H fastened to it and a wormwheel G loose upon it, except when clamped by a pinch-bolt through the handle H. This pinch-bolt has a wedge-shaped head which plays in the annular slot *g* of the wormwheel G, and a pinch-nut *h* outside of the handle H. By tightening *h* the wedge-shaped head of the pinch-bolt is jammed in the annular slot *g*, and the handle H is clamped firmly to the wormwheel.

The automatic feed motion is taken off the spindle A by a belt working upon the cones *j* and J, the larger of which, J, is fast upon the rod K, and, by revolving it serves to drive the worm screw L, when clamped thereto by the friction disc M and pinch-nut N in the conical handwheel Q. When thus clamped the screw L causes the wormwheel G to revolve. When the pinch-nut *h* is slack the carriage C, and with it the drill, may be thrown upward and downward rapidly or slowly at will by means of handle H, pinion *e*, and rack *f*. When the pinch-nut *h* is tightened the carriage may be traversed slowly, either by hand, by means of the conical handwheel Q, or automatically by tightening the pinch-nut N.

It is to be observed that in releasing the feed motion to run the drill up, the operator's hand, after releasing the pinch-nut *h*, is in exactly the right place at the handle H. Also in bringing down the drill to the point at which it is to have the feed put on, he has no additional movement of any kind to make. It will also be noticed that the handle H, by its pinion *f*, takes hold directly of the carriage with no idle gears to be driven as in the usual quick returns, and that the extremity of the spindle A guided by a traversing carriage C with long bearings, never protrudes from its bearings. The drill is always equally distant from its support, and must therefore drill a true hole.

The machine is provided with a table swinging upon its column in the usual manner, but also traversing upon its bracket by a screw. The slide is arranged with a socket in such a manner that the table can be removed and a convenient clamping vice secured in its place, also a pair of centres or an angle plate as may be required for various work.

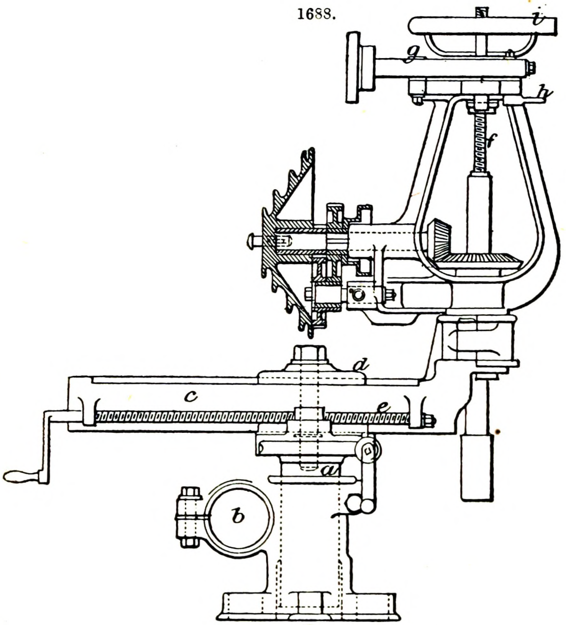


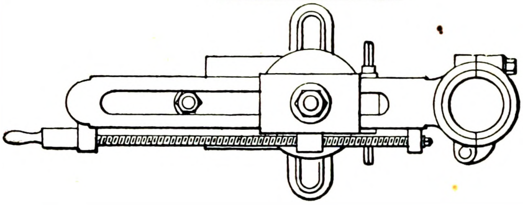
1687.

Portable drills are especially designed for use upon pieces of work of irregular form, or which from their size cannot be readily adjusted under a stationary drilling machine. Figs. 1688, 1689 show a side view and plan of the largest size machine by Thorne, De Haven, and Co., Philadelphia. It is mounted on a short cast-iron standard with a cruciform base, the latter being provided with slots through which bolts pass for securing the drill to the work. The post *a*, carrying the drill, is held either in the vertical bearing in the base, or for horizontal work it is placed in the horizontal bearing *b*. The radial arm *c* is held in position in the post by the bolt and plate *d*, the drill being traversed to and fro by means of the screw *e*, and rotated by a worm and tangent wheel. The end of the arm is furnished with a socket which carries the drill frame, and it can be turned round so as to bring always the cone pulley in a line with the driving belt.

The drill is driven by gearing, either direct from the cone, or through a system of back gearing shown in section, Fig. 1688. The automatic feed is obtained from a small pulley on the main cone pulley-shaft, a strap passing from the former to a small pulley above, which drives a worm and rotates a nut, through which the screw spindle *f* passes. The worm is hinged at *g*, and can be thrown out of gear by turning a small eccentric at *h*, and the feed can then be worked by the hand-wheel *i*. In the smaller machines, as in Fig. 1693, the back gear is omitted, and the drill is driven direct through the bevel pinion on the cone pulley-shaft. In one form also, the bearing in the end of the arm, instead of being cylindrical is made spherical, and the drill is mounted on a spherical boss, held in the bearing by a collar; when this latter is in position, the frame can only be rotated in a horizontal plane, and the spindle is kept square with the base, but if the collar is removed the frame can be set at any angle desired. This modification has many useful applications in drilling irregular forms.

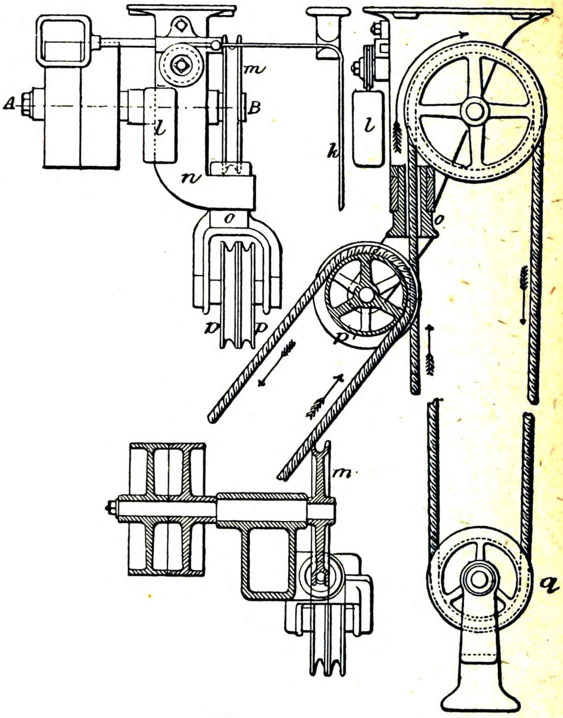
1688.





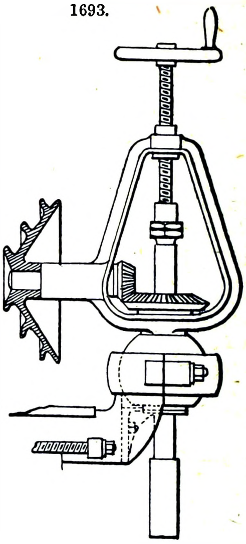
1689.

1690. 1691.



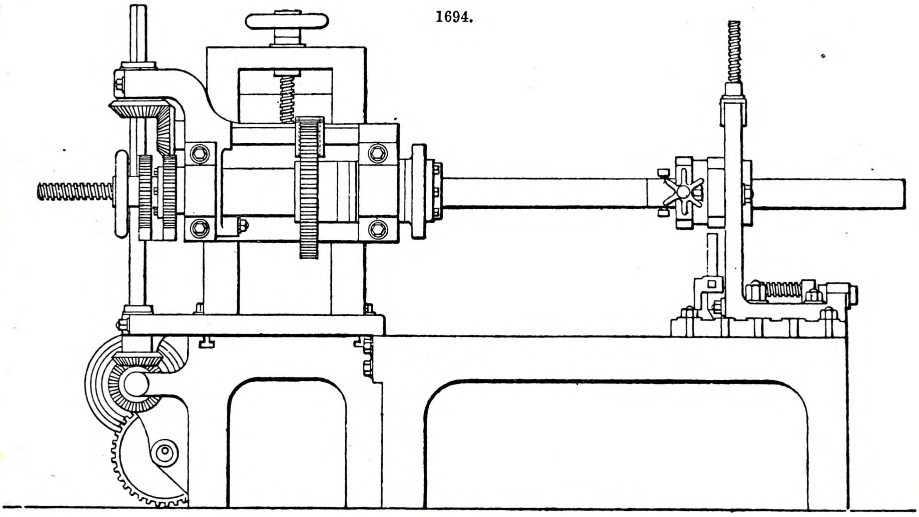
1692.

1693.



The mode of driving this drill is very ingenious, and is shown in the illustration, Figs. 1690 to 1692. The countershaft is driven by a strap passing through an eye, and which is shifted to the fast pulley when the cord *k* is pulled and held in position, the weight *l* always tending to throw the strap to the loose pulley. On the other end of the countershaft is a grooved pulley *m*, over which the cord passes which actuates the drill. Below this grooved pulley is a frame *n*, supporting a swing hanger *o*, the centre of which is hollow, as in Fig. 1690. In this swing hanger are two idle pulleys *p*, so placed that the delivering edge of one of them is always in line with the receiving edge of the grooved pulley. The cord passes under the pulley *p*, over the grooved pulley, through the hole in the hanger *n*, and then hangs down, being kept tight by a weighted pulley *q*; it then passes around pulley *p'*, and over the cone on the drill. The weighted pulley is used so that as the drill is moved to varying distances from the countershaft, there may be an extra length of driving cord available. If more is required additional lengths can be added by hook-and-eye connections.

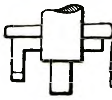
Fig. 1604 is a special tool, designed by Hind and Son, Nottingham, to facilitate the boring and facing of engine cylinders and the like. The machine consists of a strong bed, upon which is fixed a vertical slide adjusted by screw and nut, and fastened by bolts and nuts in the tee-grooves. Upon this vertical slide is mounted a strong headstock carrying the boring sockets. This headstock is also adjusted by a screw vertically; the socket runs in parallel bearings, and is driven by a spur wheel $1\frac{1}{4}$ in. pitch, 4 in. broad on face, keyed on to the socket; the wheel is driven by a pinion, receiving its motion by mitre-wheels connecting the horizontal shaft with the vertical shaft, and the vertical shaft is driven by mitre-wheels on the lower horizontal shaft having bearings in the bed of the machine. The shaft has double power gear, and a 4-speed cone, thus allowing the headstock to be adjusted in the vertical and transverse movements. The boring bar is fed self-acting, by a screw deriving its motion from a series of wheels driven from the end of the boring socket, and is furnished with a wheel for adjustment by hand.


1694.

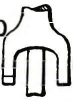
The bed to receive the work is fixed at right angles to the transverse movement of the headstock, it has a planed surface and slot holes to bolt work down. There is a boring bar-stay and apparatus for facing the ends of the cylinders, at the same time the boring operation is proceeding. This consists of a base-plate adjustable and fastened to the bed, upon which is a vertical slide or bracket, adjusted in the bottom plate by a screw and bolted to tee-grooves; upon this bracket is a crosshead and bearing to stay the boring bar. The crosshead is furnished with two tool-holders, capable of being worked to or from the centre of bar or crossheads by a self-acting tappet motion acting on a star-wheel working the screw in the crosshead. The facing apparatus can be disconnected from the boring bar when not wanted, and can be adjusted vertically to suit height of boring bar. This machine will bore holes up to 16 in. diameter, traverse the boring bar a distance of 2 ft. 6 in., and admit articles on the table up to 28 in. centres. The machine can be made to admit greater lengths and heights, and can be furnished with one or more boring heads, either on one side of the work table or at right angles for boring holes at right angles to each other, over any specified area. The machine can also be used as a turning and facing lathe for various articles, by fitting a suitable chuck on the boring socket, and fixing a compound slide rest on the bed of the machine.

The operation of drilling or boring tube holes through boiler plates and other similar work is a somewhat complex and costly process by the ordinary methods in use. We will assume, as an example, that a 3-in. hole is to be drilled accurately to a circle marked out on a tube plate $\frac{3}{4}$-in. thick. It is usual to drill, say a $\frac{3}{4}$-in. or $\frac{7}{8}$-in. hole in the centre with an ordinary drill. This hole, which is to act as the guide for the accuracy of the subsequent work, must of necessity be carefully drilled in the exact centre, to a circle first set out on the plate, and it is well known that drills are very apt to run this way or that way, according either to the form in which they are ground, or according to the perfection or imperfection of the centre punch mark from which they start, or from the defective condition of the drilling machine itself, any of which causes, or all combined, will produce irregular work. This central-hole drill labours under the disadvantage of all ordinary drills as compared with cutters, inasmuch as considerable pressure is required to force the centre or V edge of the drill into the iron, to the extent of the thickness of the shaving or drilling taken off by the cutting edge at each revolution of the drill; and the blunter the drill the greater is the pressure required to enable the drill to cut at all. Added to this, the hole through a $\frac{3}{4}$-in. plate is not complete till the drill has been fed down through a depth of 1 in. or $1\frac{1}{8}$ in. or more, according to the length of the V point of the drill. After this hole has been made a second work has to be done, and generally this is performed by a cutter specially made for the purpose, either of one of the shapes, Figs. 1695 to 1697, or of some such form. In these cutters the centre portion is supposed to fit the hole first drilled, and be the guide to ensure a true hole of the larger diameter. As often as not, however, the central pin does not fit the hole well, a defect which, whatever may be its origin, ends in the result being either a bad hole, or one out of its proper position, or even a combination of the two.

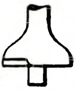
1695.



1696.



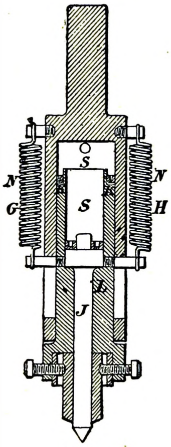
1697.



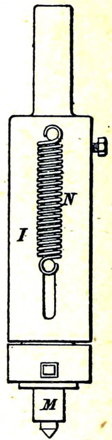
McKay's drill is designed to overcome these defects, and this with a minimum of setting out, a less amount of machine power, and in the shortest time possible with a given thickness of plate and diameter of hole.

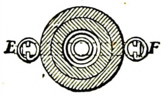
Referring to Figs. 1698 to 1701 it will be seen that it consists of a main body, of which the upper end is turned to fit the socket of a drilling machine, while the lower part forms a cylinder or case containing a small ram. Into the ram L, there are two short studs screwed through two slots formed in the outer case, by means of which a pair of spiral springs keep the ram fully home till caused to move, and draw it home again when the movement is over. This ram is also bored out from its upper end and contains an inner plunger of steel, having a shoulder J at its upper, and a pointed centre at the lower, end. L and J are each fitted with an hydraulic leather within the case. A small hole at the top of the chamber S, permits the tool to be charged with water or oil, and when the hole is closed by a screw-plug, the apparatus will be ready for work, with the exception of putting in the required cutters M according to the size hole to be cut. The centre point being placed upon a centre-punch mark made on a plate to be drilled, and the pressure of the feed of the machine brought down upon the case, J will move upwards within the cylinder S, and the oil having no way of escape presses hydrostatically within the chamber and forces the larger plunger downwards. The cutters M are thus brought down to the surface of the plate, while the centre remains also in the centre mark. If the machine is now started, the feed pressure will cause the cutters to perform their cutting work, while the centre pin still remains upon the first centre. So soon as the cutters have passed through the plate, and if there is no resistance underneath, the central pin will at once push the core down by the hydrostatic pressure due to the resistance afforded by the two external springs, which will draw the larger ram home directly the hole is made.

1698.

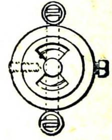


1699.





1700.



1701.

In this tool the cutters are differently formed and are also more easily constructed, and the equal pressure exerted by the fluid on each ram ensures a fair division of labour, seldom rightly obtained by such forms of cutters as at first described. The results of the use of this boring tool are, first, perfect accuracy of position when once a clean and deep centre-punch mark has been made; secondly, a true hole with a minimum quantity of metal cut away by cutters; thirdly, the work performed is done in the least time compatible with the circumstances of the case.

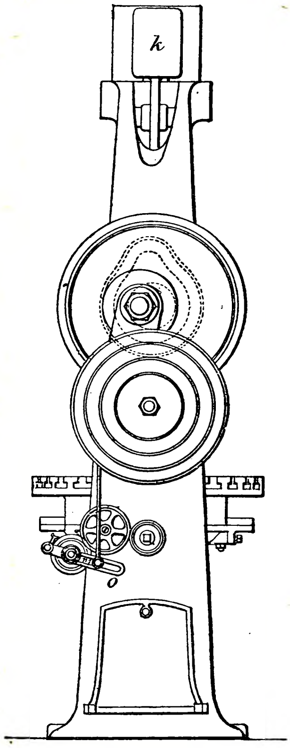
The tools for tube-hole boring, supplied with each holder, are made so as to cut holes varying $\frac{1}{8}$ in. in diameter to suit the two ends of boiler tubes. Thus a 3-in. size is arranged to cut both 3-in. and 3$\frac{1}{8}$-inch holes, and so on.

Slotting Machine.—The slotting machine of W. Sellers and Co., Philadelphia, Figs. 1701* to 1704, has sufficient over-reach to enable it to slot the eye of a wheel 48 in. in diameter. The slotting tool is operated by means of a crank driven by what is known as the Whitworth motion, giving a slow movement under cut and a quick return. The crank is adjustable in length of stroke, the maximum being 12 in. This adjustment is effected by a screw *p* in the crank plate, the adjustment of the connection of the connecting rod with the slotting bar is also by means of a screw *p'*, so as to regulate the position of the slotting bar in height from the table upon which the work rests.

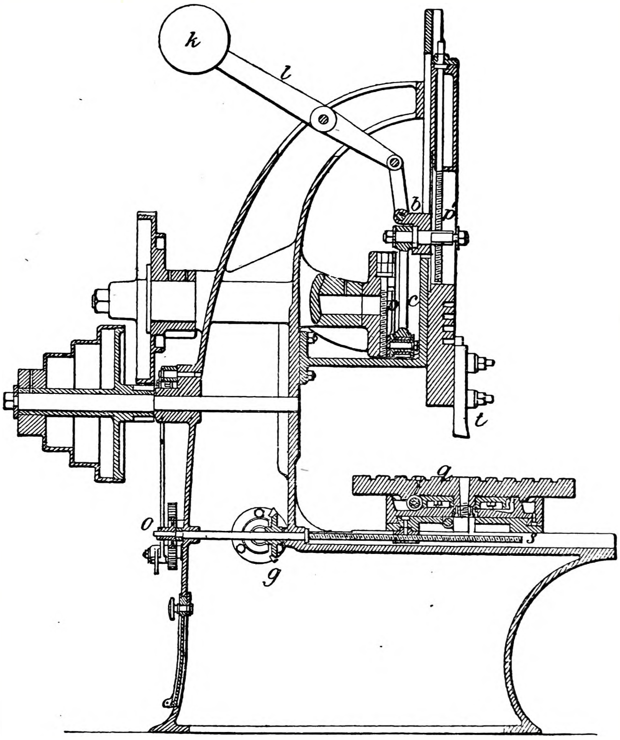
The attachment of the connecting rod *c* to the slotting bar is by means of a wrought-iron block *b*, always in connection with a counterbalance lever *l*. The counterbalance *k* is in excess of the weight of the slotting bar and any ordinary cutting tool, so as to take up all lost motion, and steady the operation of the machine under cut. The bearing or slide carrying the slotting bar is adjustable to suit the different heights of work, and enables the bar to be guided as near the work as possible. When the nature of the work will permit, the supporting bearing can be carried quite close to the table, thus giving a firm backing to the tool during its whole stroke, and ensuring steadiness of motion. It is noticeable that the connection of the connecting rod to the slotting bar is off to one side of the centre of the crank, on the pulling down or working side of the crank. This places the crank and connecting rod in the best relation for work, with the least side strain on the vertical slide under cut, while on the upstroke its consequent increased obliquity to the line of motion does no harm. The compound table *q* upon which the work is bolted consists of the usual compound slide rests of broad surface, with a rotating table on top of the upper cross slide, all provided with automatic feeds. These feeds are obtained from one primary motion *o*, a ratchet feed wheel operated by a cam at the back of the large driving wheel. This cam is so constructed as to ensure the occurrence of the feed at the top of the stroke, while the crank is passing its dead centre.

The conveyance of this feed to any required part of the machine is effected by means of one gear wheel *g*, Figs. 1702, 1704, with a square hole in the eye, to fit on the square ends of the various feed screws and shafts. Thus for the longitudinal feed this wheel, placed on the end of the feed screw *s* at the back of the bed, Fig. 1704, gears into a wheel between the rachet wheel and this screw, while the cross feed and circular feed are driven from a wheel travelling with the compound table, and driven from the rachet wheel by bevels, and having its pitch line the same distance from both of the two shafts, so as to be within reach of either with the same wheel. The longitudinal feed by hand is obtained by bevel wheels within the bed, and a squared end for a crank within reach of the workman when he is handling the other feeds. There is scarcely any machine tool requiring more close watching on the part of the workman on the class of work it is required to do; it seldom takes long cuts, it generally being but a little while under power feed at a time, and

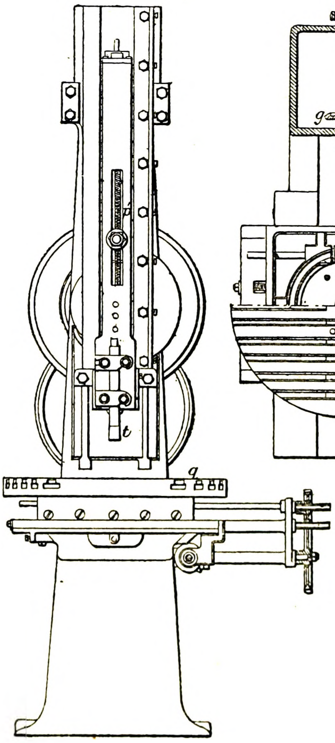
1701*.



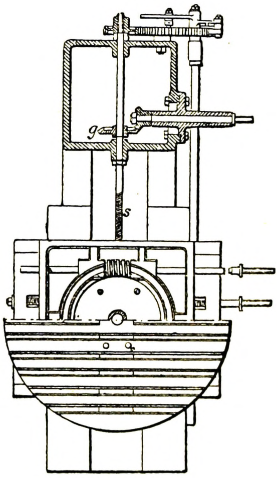
1702.



1703.



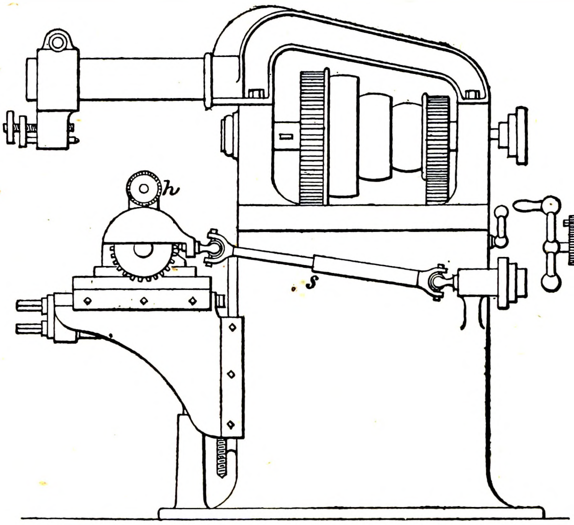
1704.



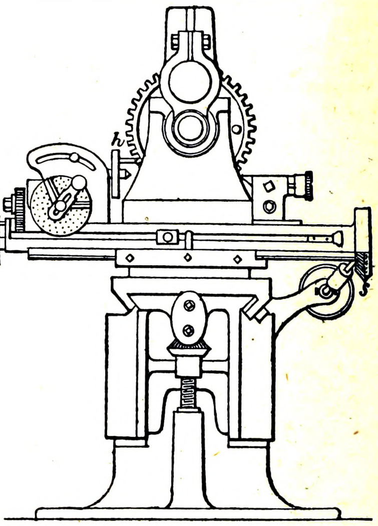
the amount of production, all other things being equal, depends upon the readiness with which the attendant workman can do his part of the movement, in adjusting and readjusting the work in various positions, and keeping the tool under cut as much of the time as possible. This can be illustrated in one class of work in common practice, namely, the key seats of wheels. Care is required to adjust the wheel in place, so as to have the sides of the key seat parallel with a diameter line. This requires some little time, while but few strokes of the slotting tool are required to cut the key seat after it is made ready; it is evident that convenience of adjustment in such work will materially influence the amount done.

Milling Machine. — Figs. 1705, 1706 show a milling machine made by the Brown and Sharpe Manufacturing Company, Lowell, Mass.; the feed motion is communicated to the carriage through a small telescopic shaft *s*, fitted with Hook's joints, so that the slide in which the carriage moves may be set at an angle with the centre line of the spindle. The small headstock *h*, carrying the centre at the end of the carriage has also an angular motion in the vertical plane, so arranged that whatever the angle may be the centre remains in gear with the feed motion. These additional movements render the machine capable of a wide range of application, for besides ordinary milling a great variety of other work, such as reamers, twist drills, milling cutters, and rosebits, may be produced, and the teeth of spur and bevel wheels may be also cut. The cutters used in these machines are of peculiar shape, and are of the same cross section throughout, so that by grinding them on the face they may be sharpened without altering their form. Machines having rotary cutters with detached teeth are sometimes used for operating upon a larger class of work, where it is necessary to take heavy cuts.

1705.



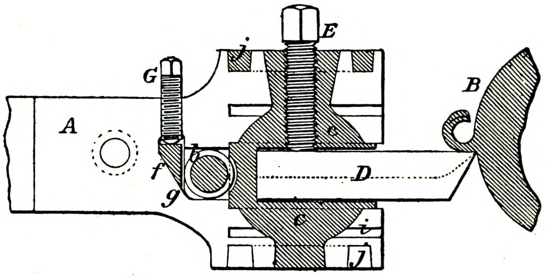
1706.



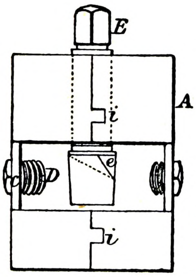
Tool-Holders.—Machine tool-cutters formed of comparatively small pieces of steel held in special tool-holders in place of the ordinary tools, forged from steel bars of various dimensions, are largely employed.

Figs. 1707 to 1716 are of Baville's system of tool-holders, as made by Greenwood and Batley of Leeds; Figs. 1707, 1708 are adapted for lathe tools. The tool is shown in longitudinal section,

1707.



1709.



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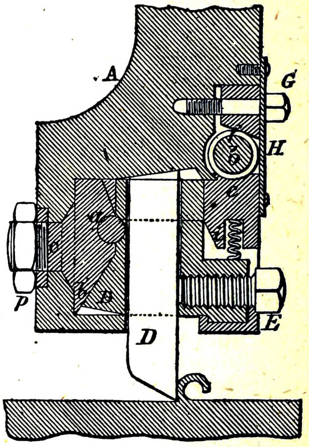
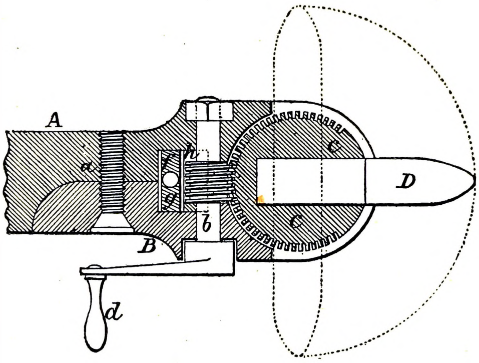
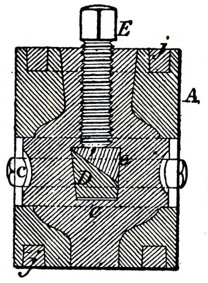
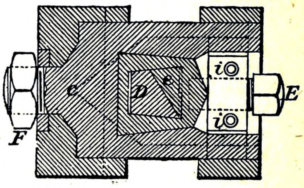




1708.



1711.

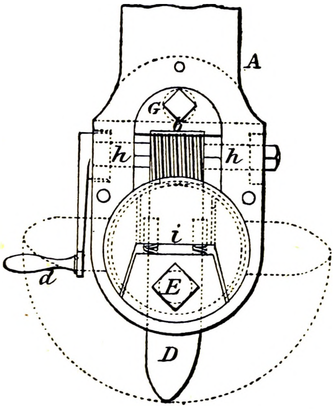


1712.

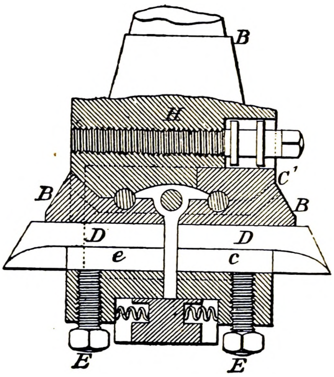
Fig. 1707, horizontal section, Fig. 1708; it consists of two main parts A and B fitted together and fastened by screws *a*, so as to present a cylindrical head, in the interior of which is placed the movable nut-shaped piece C, which holds the cutter D; this nut fitted exactly to the receptacle formed to hold it, in the interior of the parts A and B, is of a spherical shape in the middle, with a conical part above and below, terminating in a cylindrical tenon forming two pivots, on which it can make a rotary movement of half a circle. The circumference of this sphere is cut with a thread gearing into a worm *b*, the journals of which are made square at the ends to receive a handle *d*, by the aid of which it can be turned. In order to hold the tool firmly, C is pierced by an angular opening, Fig. 1707, corresponding to the section D of the cutter, which fits in very accurately, leaving room, however, for the insertion of a wedge-shaped piece, which is screwed down tightly by the screw E.

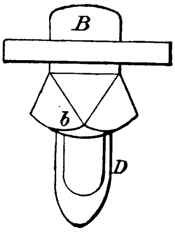
A tool like this can act at will perpendicularly or parallel to the axis of the lathe, or in any of the intermediate oblique positions; further by means of its simple form and mobility, it can be employed in working on certain interiors, ordinarily requiring a tool forged to a special shape.

1713.

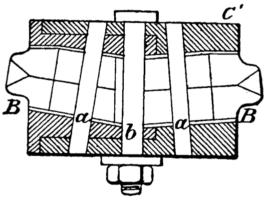


1714.





1715.



1716.

A brake is therefore applied to the axis of the worm *b*, in such a manner as to ensure the rigidity of the nut C in any desired position; this brake consists of a wedge *f*, acted upon by means of the screw G, so as to press it by the interposition of the plate *g*, Fig. 1708, on the two half journals *h*, embracing the axis of the screw half its circumference. The two jaws A and B are joined very accurately one upon the other, by means of two tenons which go into the grooves *i*, Fig. 1707, and in addition to the screw *a*, the two parts of the head of the tool-holders are fixed together above and below the nut, by means of two rings *j*, fitted in like grooves.

In the tool-holder for planing machines, Figs. 1709 to 1712, the same general features in principle are observable as in the preceding one, but it has in addition a small special mechanism, so arranged as to permit of the tool being slightly inclined on the return stroke, in order to prevent it from becoming blunt, by rubbing on the work in going backwards previous to commencing a new cut. The majority of planing machines are so constructed as to do this, but the whole tool-box has to be inclined, whereas in this case it is only the cutter which needs moving, and being very light the cutting edge does not get blunted by the friction so soon as in the machines now in use, there being less weight of tool-box on the edge of the tool.

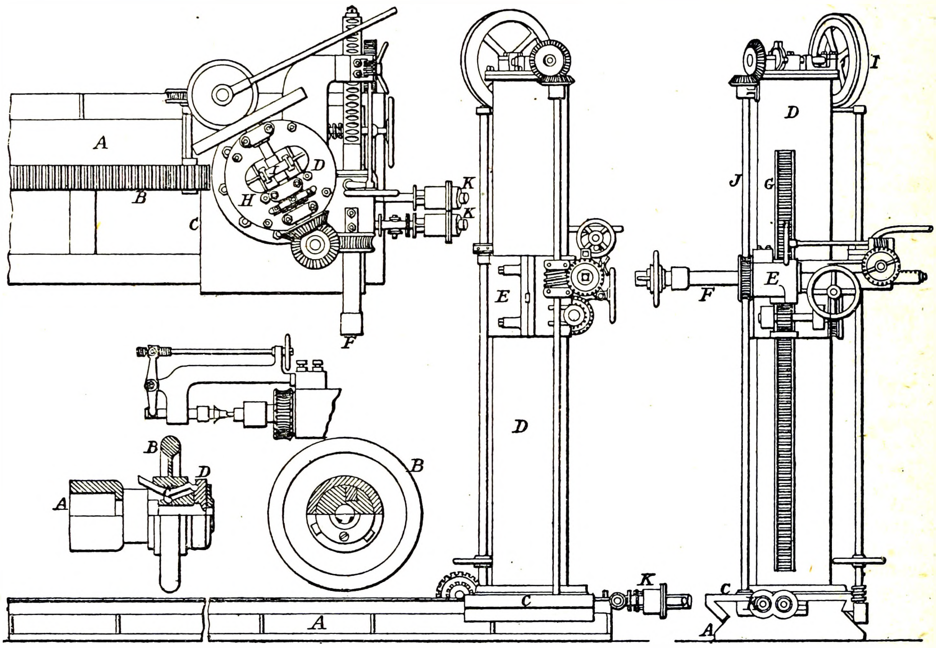
This planing tool-holder is shown in vertical section, Fig. 1710. Fig. 1712 is a sectional plan, and Fig. 1709 a back view of the box to receive the tool. It is composed of a vertical piece A, terminating in a cylindrical part in which the head C is adjustable; this as in the preceding case can rotate by the action of the worm *b*, and is widened out to receive the tool-box B, in which the tool D is held by the screw E. The tool-box B does not fit close into the space left to hold it in the head C; this permits a slight oscillating movement on the steel pin *a*, fitted half into each of the two pieces, Fig. 1710.

When cutting, the tool-box B occupies the position, Fig. 1710, and takes its bearings on the head at the angular parts, *b'*, Fig. 1710, so as to maintain the rigidity of the cutter by its adjustment. In the movement in the contrary direction, the simple contact of the cutter on the piece under operation is sufficient to make the tool-box B, rotating on the pin *a*, reverse itself and give the necessary inclination, and further to provide against the tool-box B being shaken in its various motions, the two springs bring it back constantly to the proper working position. The upper part of the head C is toothed to gear into the worm *b*, by means of which it can rotate in its own bearings and give the desired position to the cutter; it terminates with a screwed end on which the tightening nut F is fitted so as to hold it firmly in the tool-holder. The worm is also provided with a brake composed of the screw G and wedge *f*, which act on the journals *h*, clasping the screw spindle. The different parts are covered by a plate H, Fig. 1710, screwed on the tool-holder.

Figs. 1713 to 1716 are of a double tool-holder with horizontal cutters for a slotting machine. This latter tool-holder, by its conical piece B may be fitted on the head of any kind of slotting machine, but is specially arranged for slotting axle boxes. For this purpose it is made double, that is to say, provided with two cutters D and D′, placed horizontally, and in such a manner as to work simultaneously; each one is fixed in an oscillating box, one of the boxes being fixed in the slide rest C′, moved by the screw H, by means of which the extreme distance between the two cutters can be adjusted at will; Fig. 1716 shows a sectional plan through the pins *a*, and shows the centre bolt *b*, which is used to assure the firmness of the block C′, with the conical head B. These two pieces carrying the movable parts, constitute the whole of the tool-holder.

Machine for Fixing Boiler Stays.—In the manufacture of steam boilers when the shell has been drilled it is taken apart, and all the drill-burrs removed from the plates. The outside and inside edges of the holes are countersunk by machine. The plates are put together again and riveted up. The next step is to lower the furnaces and combustion chambers into the shells, to which the front plates are riveted. The screw stay holes are then drilled and tapped, and the stays are screwed. Fig. 1718 is an elevation; Fig. 1717, a plan; Fig. 1719, an end view; and Fig. 1720, details of a machine invented by Allan, of Sunderland, for this purpose. It consists of a hollow pillar D, inside of which is placed a small steam engine, with a fly-wheel I; up and down the pillar slides a saddle E. This is reversed and lowered by a rack and beam. The pillar is moved on the bed A of the machine on the inverted V foot C. Steam is introduced through flexible pipes and stuffing boxes J, and the various movements of the machine are controlled by one man working the hand-wheels. The bar F, Fig. 1719, carries the holder, shown to a large scale in Fig. 1720, which is arranged to rotate, and can at the same time be drawn backwards and forwards at will by the rack.

1717. 1718. 1719.



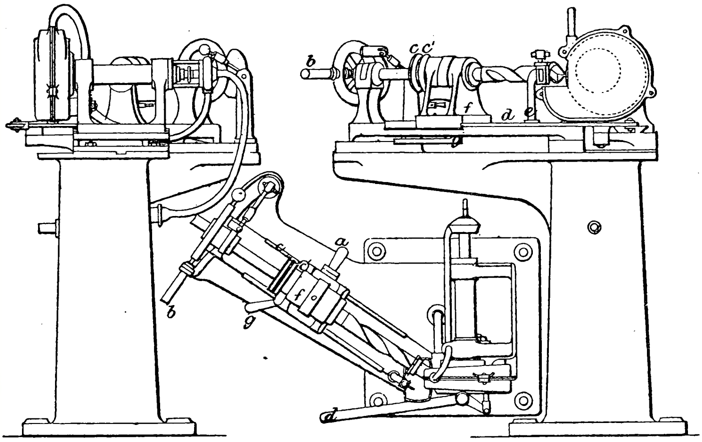
1720.

The boiler is laid down and levelled, with the back end close to the bed-plate. The pillar can then traverse back and forward across the end of the boiler. A drill is then put into the end F, and the machine being started, the holes are drilled one after another in the two plates true and at right angles to the boiler plates. The drill is moved over the boiler end by the gearing F, which is made either to raise or lower the saddle E, or to move the whole pillar back or forward. When the holes have been drilled, a tap is substituted for the drill, and they are screwed. Next the stays are substituted for the tap, and put in place, and finally a cutter-head is placed on, and the stay ends all cut off accurately to length and shape.

Emery Grinders.—The cleanliness of emery wheels, and their quick cutting character, compared with natural grindstones, render them convenient for sharpening tools. They are used to a considerable extent for sharpening saws, mill picks, paper-cutting knives, lathe tools, drills, and shear blades, and are found to impart a better edge to the tool than a grindstone. In Van Haagen's twist drill grinders, the drill is placed in a chuck that presents it at the proper angle to the edge of the wheel, and by an ingenious link connection, the same movement of the handle for turning the drill round, also gives the proper motion for backing it off behind the cutting lip. A small centrifugal pump keeps the wheel supplied with water, which is prevented from flying off by a hood that covers the wheel, except at the cutting point.

Figs. 1721 to 1723 are of this twist drill grinding machine, constructed by Thomson, Sterne, and Co., of Glasgow. It consists of a hollow standard having at its top a slide for the headstock carrying the emery wheel spindle. This headstock can be moved to and fro on its slide by the lever *d*. The spindle carries at one end the emery wheel, while at the other it drives a small centrifugal pump, which draws water from the hollow standard serving as a water tank, and discharges it on the edge of the emery wheel, the connections between the pump and the tank and emery wheel casing, respectively, being made by indiarubber tubing. The wheel is so mounted that it can be shifted back as the emery wheel wears, and the water can thus always be discharged effectively on the wheel. The wheel spindle is driven at a speed of about 2400 revolutions a minute.

1721. 1722.



1723.

At an angle of 45° with the wheel spindle, there branches off from the standard an arm carrying the sliding head, in which the drill to be ground is mounted. In the grinding of a drill the handles *a* and *b* are loosened. From the bearing post *e*, the finger which is used in the preliminary adjustment of the wheel is removed, and the proper size of guide ring for the drill to be ground fixed on; the drill is placed in the hollow spindle or socket made to fit the drill and spindle, its end resting in the guide ring, with the left hand of the operator on the milled flanges *c c'*; the spindle is adjusted to allow about $\frac{5}{8}$-in. play between the flange *c'* and the head *f*; the head *f* and the spindle are moved, so that the end of the drill is brought to the face of the wheel, and the lever *g* tightened with the right hand. The machine is then started, and the amount of water supply regulated by raising or lowering the flexible tube through the eye on the headstock; the drill is adjusted forward with the left hand on the flanges *c c'*, one cutting edge of the drill being brought horizontal against the face of the wheel, and the drill pressed forward until the desired amount is cut away; the handles *a* and *b* are tightened firmly; then the lever *d* worked to move the emery wheel back and forward across the face of the drill, and at the same time the handle *b* brought down very slowly; after which the drill is rotated quickly against the face of the wheel by moving the handle *b* up and down, until a smooth finish is given to the end of the drill; the handle *b* is loosened, and the spring stud pulled down underneath the head *f*. The handle *a* is thrown over, and the handle *b* tightened, the operation being repeated as in grinding the first side of the drill. After setting the handle *a* it must not be loosened until both cutting edges of the drill are finished. To prevent the water from freezing in the tank, thereby endangering the pedestal, it is recommended to add a small quantity of glycerine, otherwise the water should not be allowed to remain in the tank over-night during frosty weather.

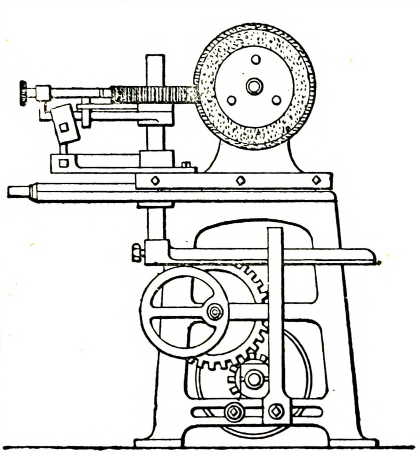
An application of emery wheels with moulded edges is shown Fig. 1724, which is a machine made by Slack's Emery Wheel Co. for cleaning out the teeth of wheels. The emery wheel is turned to the shape of the space between the teeth, and revolves in a small headstock, while the wheel, or pinion, being operated on is moved vertically in front of it by means of an eccentric motion, and at the end of each stroke is turned automatically through the space of one tooth. These machines are exclusively used by makers of textile machinery, and will clean from 1500 to 2000 teeth an hour.

A similar arrangement is used in the Universal Tool Grinders of Thomson, Sterne, and Co. One of these machines is shown in Figs. 1725, 1726. It will be seen that the centrifugal pump is placed at the back of the machine, and is driven from a pulley on the countershaft. The safety grinding ring used with these machines is made so that the sides of the emery ring are gripped between two washers with dovetail grooves in them, which would keep the pieces in position should the ring break. Corundum, which is a pure form of emery, and a harder and sharper abrasive than the emery of commerce, is used where it is important that the wheel should remain of the same diameter and shape. Morton Poole's system of grinding chilled calender rolls is an instance of the application of corundum wheels; there are several peculiar features about this process of grinding, and an extremely accurate result is obtained.

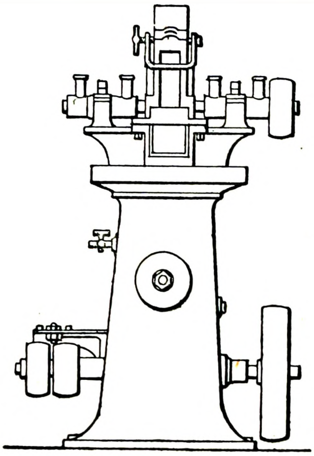
It is well known to all who have had experience in emery grinding that to perform rapid cutting a very high speed of the wheels is desirable. But it so happens that those emery compounds which are best adapted for quick cutting have also the least cohesive strength, and hence the speed at which it is possible to drive safely ordinary discs made of such compounds is limited.

To obviate this is the object of the device invented by Butler, Figs. 1727, 1728, where, instead of a disc of emery, a ring is employed made up of segments *a a*. These segments are placed within the flange b' of a casting *b*, and inside them are arranged the curved plates *e e*, which are tightened up against the grinding segments by the screws *f f*, interposed between the plates *e* and the boss *c*. The pairs of locked nuts *g g* are used for balancing the wheel, and they enable this balancing, an important matter in wheels driven at a high speed, to be accomplished very readily and accurately. Fig. 1729 relates to an arrangement differing slightly from that of Fig. 1727, the casting being, in this case, of such form that the plain disc *b* is interposed between the adjusting screws *f* and the work which is being ground. It will be understood that the grinding is performed by bringing the work against the annular surfaces a', presented by the grinding blocks instead of against the periphery of a wheel as is usual. As the surface a^1 wears away, the grinding segments are shifted further out, a portion of the thickness of the segments being made of a non-grinding compound, so that they may be held firmly until all the grinding part is utilized.

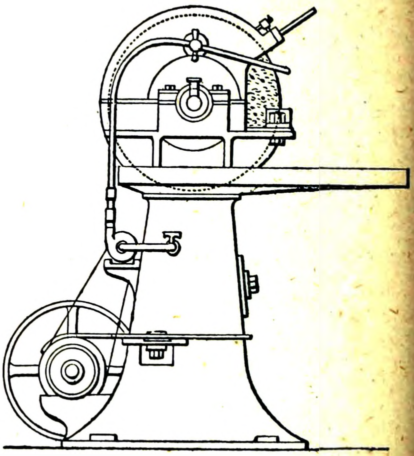
1724.



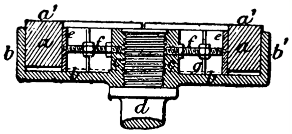
1725.



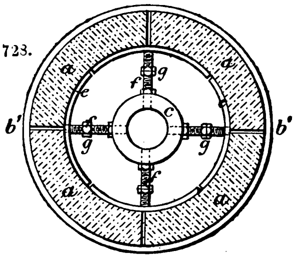
1726.

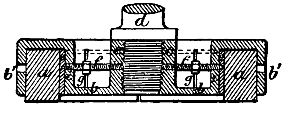


1727.



1728.





1729.

Segments held in the way described can be driven with perfect safety at exceedingly high speeds, while the manner in which they are held is such, that there is nothing about the device likely to catch against work or do damage by anything falling on it. This is an important matter concerning the safety of the workmen using the wheels.

Ransome's emery wheels are much esteemed in English works, and from the circular of the makers, A. and H. Bateman and Co., of Greenwich, we give the following practical remarks, which apply generally to emery wheels, on their use ;—

" It is well to run a coarse and a fine wheel at opposite ends of the same spindle, doing the rough work on the former and finishing up on the latter. Far more work can be got out of the wheels by applying the work lightly to them, than by pressing or crowding it; the latter only heats the metal, makes the wheel glaze, and often go out of truth.

" Speed has a great deal to do with result; from considerable experience, a surface speed of 4000 to 4500 ft. a minute, say 1350 revolutions of the spindle for a 12-in. wheel, is recommended, although a thick wheel may be run one-third faster with advantage, and good work may be got out of a slower speed.

" A foundation for the machine, good enough for slow speeds, will not do for high ones. Any vibration or tremor while at work is certain to produce bad results. It is not enough to screw a spindle firmly to a bench or table, the latter must itself be firm and rigid. In self-contained machines, a good concrete foundation is necessary; the expense will not be grudged, when the results are compared with those obtained from a machine on a shaky foundation. It must be remembered, that a large amount of centrifugal force is developed in a disc revolving many hundred times in a minute, and this must be met by firm foundations, and proper screwing up of the washers and side plates. Too much care cannot be taken on these points."

To A. and H. Bateman and Co. are also due the subjoined practical suggestions ;—

" Examine emery wheels and machinery at least once a day.

" Remedy any defects at once, and on no account go on working with anything out of order. If a machine vibrates, add or alter requisite fittings. If a wheel is chipped or out of truth, true it with a black diamond. This may be done while running at full speed, care being taken to touch the wheel very lightly. After trueing, the wheel will be dull; rough it by running it against a piece of copper, or a piece of hard coke. Do this frequently; it makes work better, and wastes the wheel far less than waiting until it is very much 'out.'

"Never let the spindle jump or get hot, either will injure the wheel and produce bad work.

"See that side plates fit the spindle, and are fairly true. Screw up firmly, but not so tight as to crush the wheel. Do not use too long a spanner, it is difficult to estimate the force applied by means of a screw and long lever.

"Be careful to run the wheels at about the indicated speed; they wear out quicker if run much slower, and are apt to go out of truth, and an unnecessary risk is run if the speed be too great. Ascertain the speed by means of a counter. Calculation by size of pulleys is not very reliable, owing to the difficulty of making proper allowance for slip.

"If working with water, let it be applied close to the work, through a small orifice in a pipe under some pressure, either from the main, or from an elevated cistern. The wind caused by the wheel will otherwise tend to blow the water away. If too much is used it will fly off and cause inconvenience. Generally, working dry will be found preferable, but for tools and small work water is necessary.

"With tools and small work, hold in the right hand and press near the end with some of the fingers of the left hand. The moment the heat becomes uncomfortable, dip the work in water standing by, and then replace it on the wheel dripping, it not being necessary to dry it. Heat that will not hurt the fingers, will not injure the temper of the steel.

"If a wheel breaks, nearly if not all the fragments will fly in the line of rotation. In grinding, therefore, stand as clear as possible of this line, to avoid injury in case of accident. Railway trains sometimes come to grief. An emery wheel running the same speed may do the same, but will not with proper care.

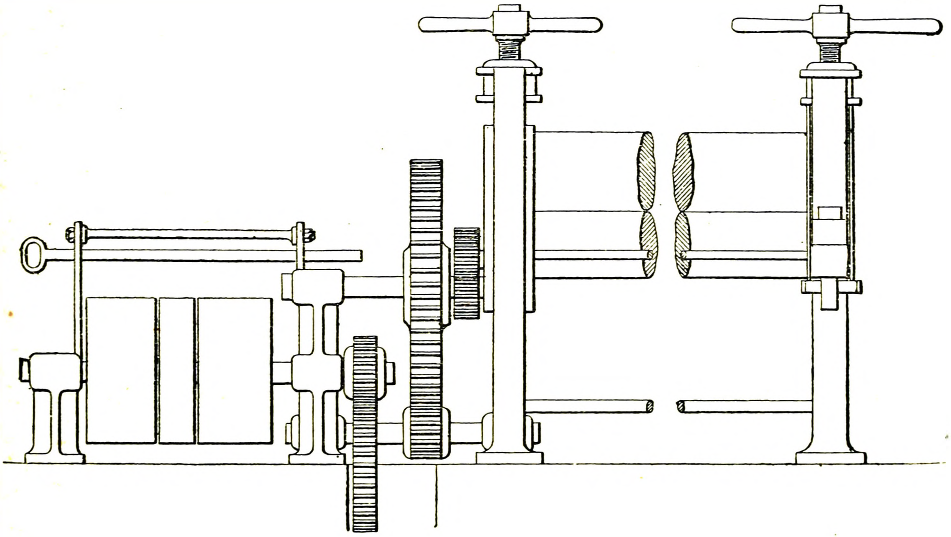
"Mount the wheels with the proper washers, and do not strip them off and put on others.

"Most important of all, remember that fair working gives best work. Forcing work against a wheel injures both, causes risk of accident, hastens the wear of the wheel, frequently causes glazing, which never happens with proper grinding, and is sure to wear a wheel untrue and involve very frequent trueing up."

There is but one limit to the use of emery wheels for fettling castings, and that is the size and weight of the castings. All castings, whether iron or brass, not too heavy or unshapely to be readily handled, should be fettled by the solid emery wheels, and it is placed beyond dispute by the experience of years, that this plan is cheaper and more practical than any other.

We see little reason to doubt that the solid wheel will in time entirely displace the grindstone. There is really no advantage in the very large size of grindstones, and the great variation between their maximum and minimum size, causes much inconvenience to the workman. The size of emery wheels is such that they occupy but little space, and are mounted with the greatest ease and speed. They are so strong that they can be run at an immense speed, and being composed of angular grains of a mineral only inferior in hardness to a diamond, they cut much more rapidly than grindstones, whose uneven texture is mainly caused by round and waterworn particles of silica. While the stones have to be roughed and picked from time to time, no really good emery wheel ever requires such treatment, presenting always a fresh, free, sharp-cutting surface. In consequence of the hardness of the surface and the very high speed, the work needs to be lightly touched to the wheel, and the selection of heavy men as grinders is done away with, as are also the swinging boards, housings, and appliances for getting pressure. Owing to the moderate size of the wheels, they can be easily turned with diamond tools, and thus always revolve as perfect circles, instead of becoming eccentric as the stones do.

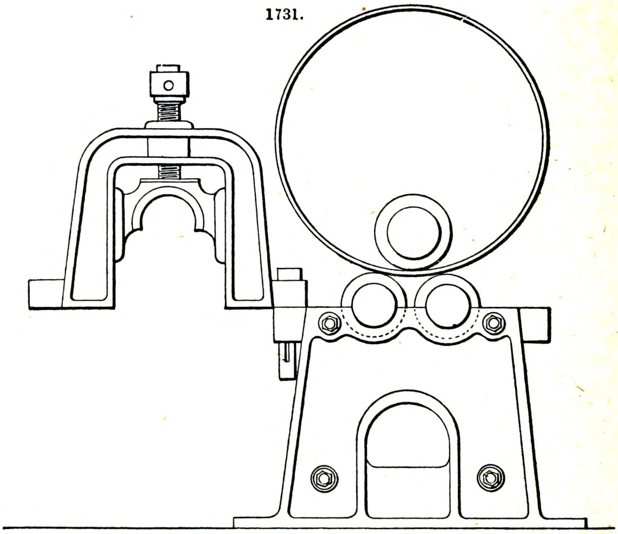
1730.



Rolling Machines.—Figs. 1730, 1731 illustrate a set of plate-bending rolls made by Grant and

Macfarlane, of Johnstone, near Glasgow. It will be seen that the upper part of the frame carrying the bearing and elevating screw is made in the form of an arch, and is attached to the lower part by two bolts; when necessary, one of these bolts may be removed, and the top frame swung clear round on the other. Bent plates may be straightened in machines of this kind by running them through the rolls, with the top roll set to neutralize the existing curves.

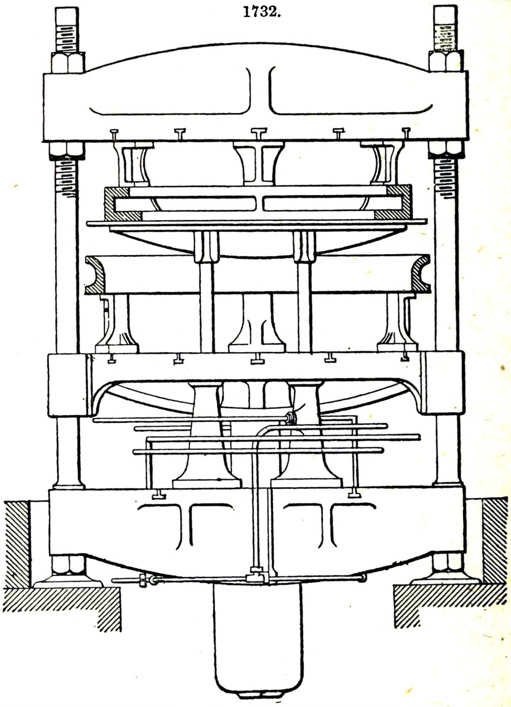
1731.



Angle-iron, T-iron, and bulb-iron may be bent in the same way as plates if grooves of the proper shape are turned in the rolls; but in the machines usually employed for this purpose the works are placed vertically, and project clear of the frame. In the machines for bending garboard strakes, the garboard strake is the line of plates next the keel of a ship, the plate to be bent is clambed to a table, and the bending-roll brought to bear upon it by a powerfully-geared quadrant at each end. Machines for flanging and preparing the edges of plates are now generally used in the best boiler works, and not only effect a considerable saving of time, but turn out cleaner work than that done by hand.

Hydraulic Tools.—For circular work, the most rapid way of forming a flange is to give a rotary motion to the work, and deflect the edge by bringing rollers to bear upon it. Where the work is irregular, and cannot be operated upon by a rotary machine of this kind, the flanging is usually performed by pressing the work between dies, on the plan of Piedbœuf's hydraulic flanging machine, Fig. 1732, a similar arrangement of hollow dies is employed, except that the movable die is fixed on the plunger of a hydraulic press.

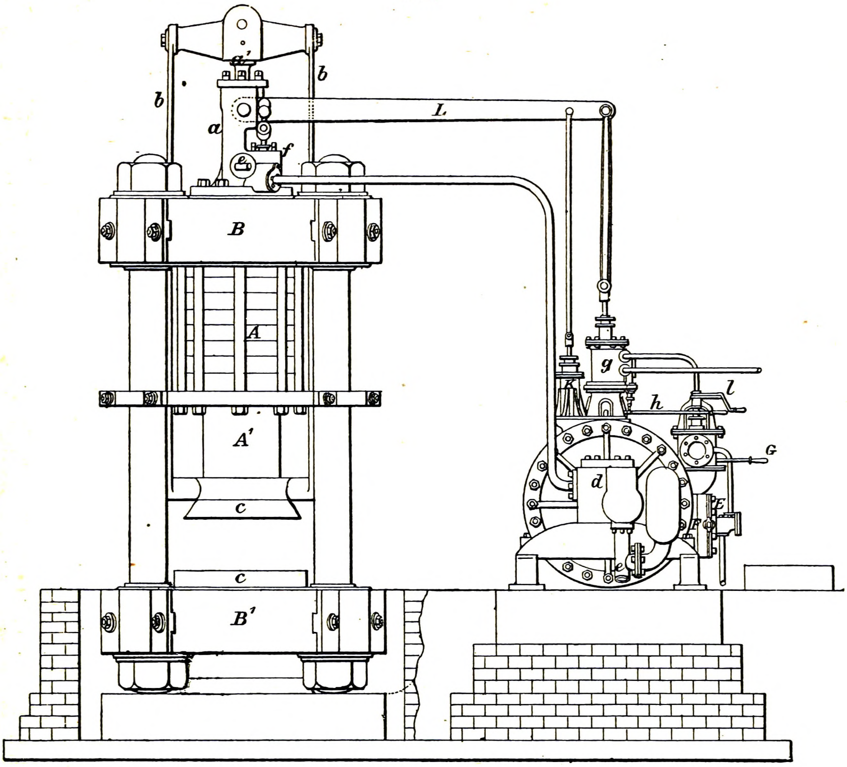
1732.



The plate required to be flanged, having been properly heated, is drawn out from the furnace over iron bars, on to the annular ring, Fig. 1732. The four small plungers carrying the table are then opened to the accumulator pressure. This table, rising up quickly, firmly holds the hot-plate against the top die, until the pressure being admitted into the large cylinder, the ram of this also rises, carrying the lower movable table, on which is attached the annular ring, on which in the first place the plate was placed till adjusted and securely held by the movable table. The ring, travelling up, catches the projecting edges of the plates to be flanged, and bends them accurately over the die. The valves of both the main and small cylinders are then opened to the exhaust. The large one falls very rapidly, owing to the weight of its parts, and the plate just flanged thus comes off the die immediately before it has had time to contract on it. One valve works all the four small, and another the large cylinder.

A variety of irregular shapes can be produced by this machine, such as locomotive fire-box ends and front tube-plates with reverse flanges, and it is stated the saving amounts to fully two-thirds of cost by hand. This is without taking into consideration the economy in being able to use plates of an inferior quality in place of high-class brands, which may be only necessary because the commoner, but equally strong kinds, would not stand the fire and working; but there is the additional saving in cost in the fitting together afterwards, in saving of fuel, and wear and tear of furnace. A $\frac{5}{8}$-in. thickness of plate and 7 ft. diameter can have a $4\frac{1}{2}$-in. or 6-in. flange put on all round in a little over 30 seconds. The only limit to the machine's performance a day is the furnace power which can be placed round it.

1733.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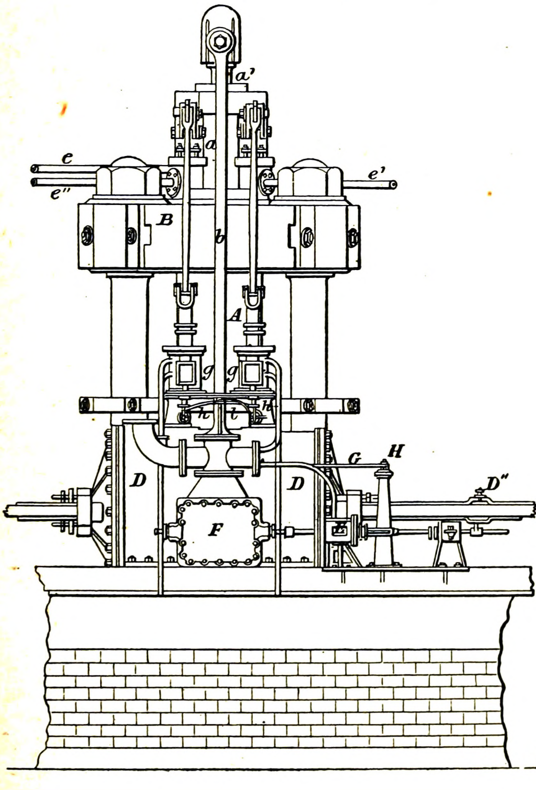
1734.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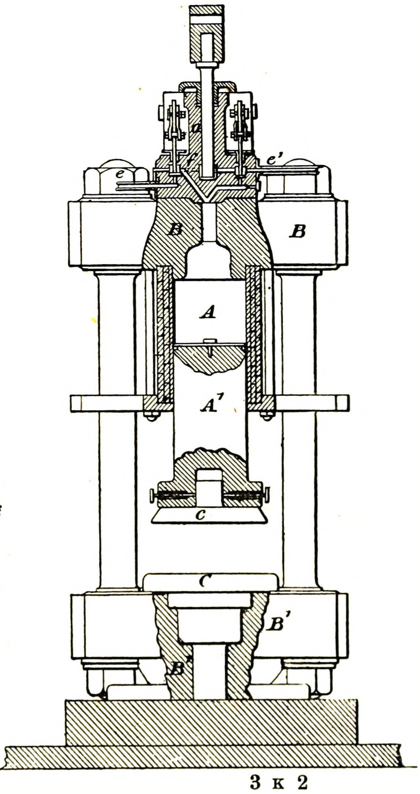
1735.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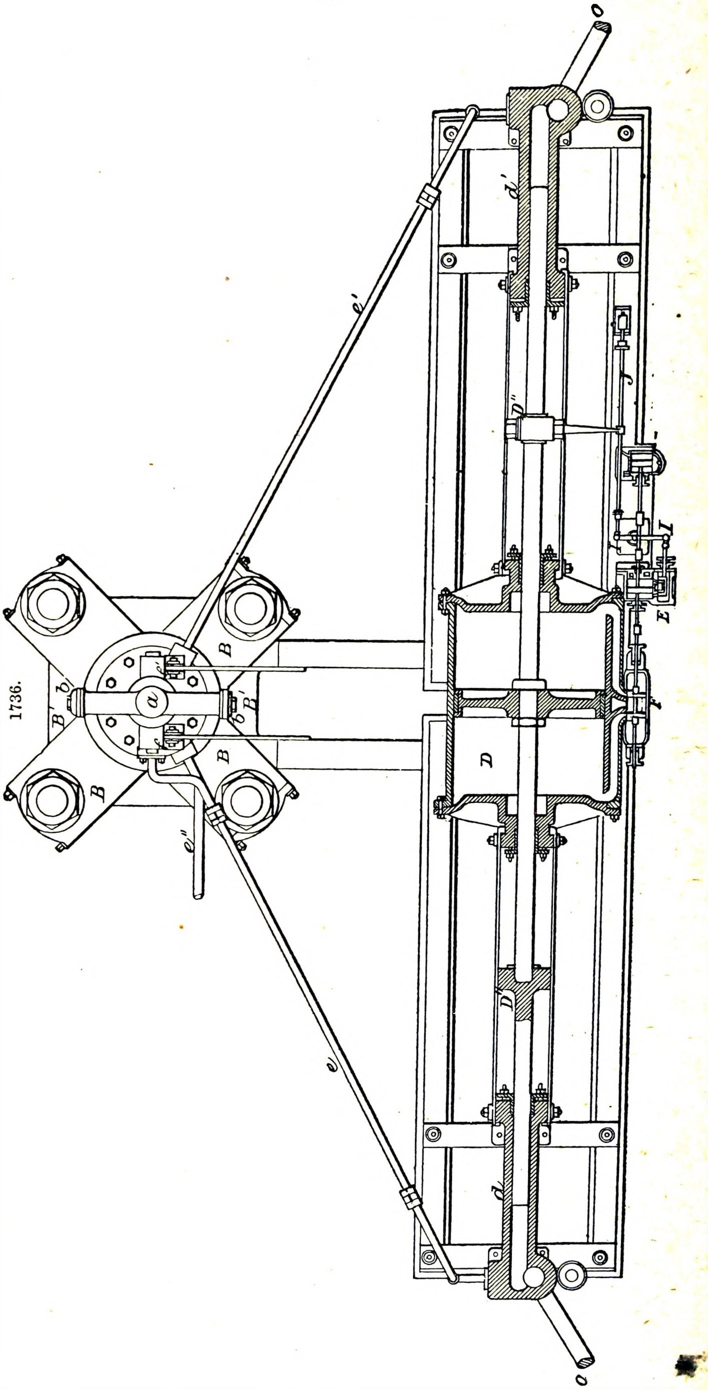
Similar results are obtained by the use of the presses devised by Haswell of Vienna which are illustrated in Figs. 1733 to 1738. The pumps are worked by a horizontal direct-acting steam cylinder, of large size, the working of which is directed by an automatic arrangement, so that it is perfectly and instantaneously under the control of the driver.

Fig. 1733 is an end view of the press and steam engine. Fig. 1734 a side elevation. Fig. 1735 is a vertical section. Fig. 1736 horizontal sectional plan. Fig. 1737 a cross-section of the steam and cushion cylinders. Fig. 1738, a horizontal section, through the chambers of the regulating valves of the press, and the attachment of the water pipes.

The press consists mainly of two vertical cylinders A and *a*, of different sizes. These are fixed to a large cast-iron frame B, of cruciform shape, supported on four malleable-iron columns, firmly secured to a bed plate B′. The two pistons A′ and *a*′ have cross heads fitted on their outer ends, connected at their extremities by two strong malleable-iron side rods *b*, so that the pistons work simultaneously. These rods, passing through grooves formed in the upper frame B, and the intermediate steadying frame B″ act likewise as guides to prevent the rams turning.

The hammer is fitted to the lower end of the pressing ram A′, and the bottom anvil bedded to the bottom bedplate B′. The main steam cylinder D is fixed horizontally on a strong bed plate, the piston rod passing through packed stuffing boxes at both ends, to which are attached, in the same line and plane, the rams of the respective hydraulic pumps.



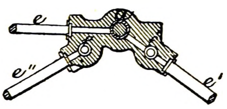
1736.

A small steam cylinder E is placed by the side of the main steam cylinder to work its slide valve. Attached to the valve rod of this steam cylinder E, by the lever I, is a tappet rod J, which is worked automatically by a projecting arm attached to the crosshead D″ of the ram of the pump *d*′, this acting upon the slide valve of the small cylinder E, which in its turn actuates the slide valve F of the main cylinder D, which works the pumps of *d* and *d*′.

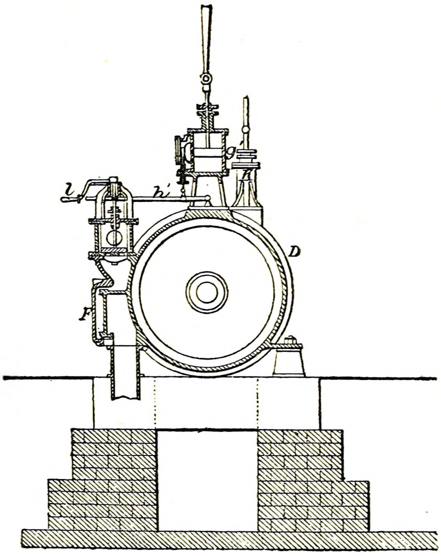
The discharge branches of the two pumps *d* and *d*′ are connected by the pipes *e* and *e*′ with the passages and chambers formed as in Fig. 1738. The inlet and discharge regulating valves *f* and *f*′, are worked by levers L L, having rods attached to their free ends, and directly connected with the piston rods of the two small auxiliary steam cylinders *g* and *g*′. The slide valves of these auxiliary cylinders are controlled by means of the hand levers *h* and *h*′.

The small cylinders K are charged with oil, and have perforated pistons, the rods of which are also connected to the regulating valve levers L L. These relieve the sudden shock incident to the

1738.



1737.

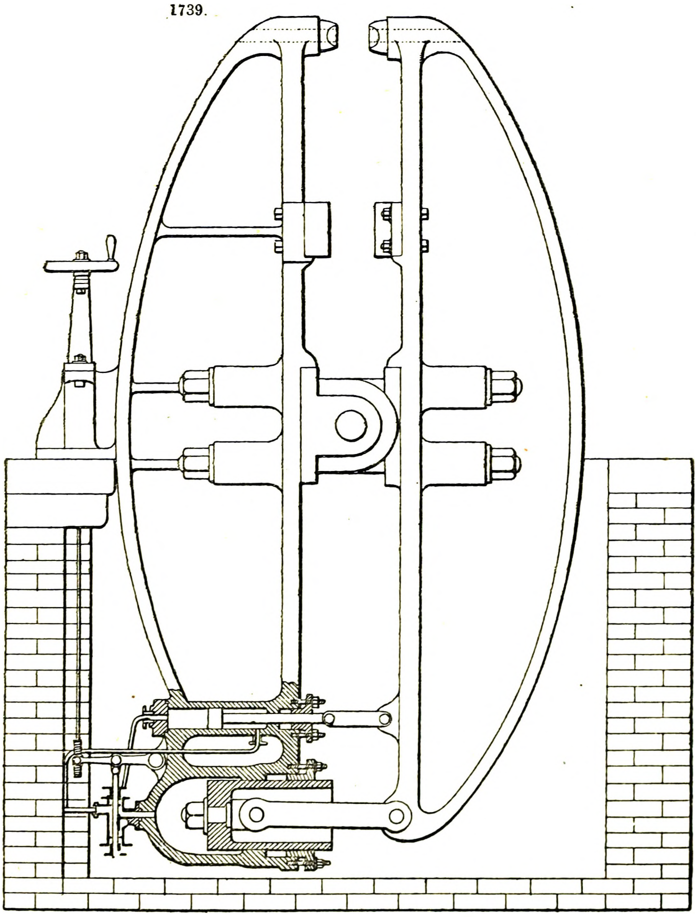


work put upon the levers. There is also a loaded safety valve, not shown, placed in a convenient position on the pressure pipe, for relief in case of need.

The press may be worked at any desired pressure, regulated by the boiler steam pressure, and either a light or heavy blow, or squeeze, can be given to suit the work in hand. The velocity or number of strokes a minute, depends upon the efficient action and rapidity with which the two auxiliary cylinders *g* and *g'* can be worked, as these regulate the inlet and escape valves *f* and *f'*, the driver having merely to handle the levers *h* and *h'* of the slide valves. No expensive foundations are required, as both the engine and press are self contained.

The slabs swaged by this press are always hammered to some extent before being put into the mould, and similarly to all special tools, Haswell's press can only be used at a pecuniary advantage for work in which there is repetition. In such cases the saving is very great, as for instance with locomotive cranks and wheels, it may amount to as much as 50 per cent., and even more, as compared with forgings finished under the hammer.

1739.



McKay and Macgeorge's 60-ton hydraulic riveting machine, Fig. 1739, consists chiefly of two levers, each 12 ft. long, the left-hand lever being stationary, and carrying the hydraulic cylinders, whilst the other turns upon a centre and advances or withdraws the dies from the work. In consequence of the levers being of so large a radius, the arc described by the end of the movable one is for all practical purposes a straight line, and no inconvenience results from the obvious theoretical objection that the movable die travels in the arc of a circle. Both cylinders and working parts are quite out of the way, being placed beneath the ground within a pit, which is carefully closed, and so protected from frost, as well as from danger of injury, accidental or otherwise. Guarding against frost is a very great consideration, as hydraulic cylinders are often left full and become liable to burst through their contents freezing in winter.

The machine is actuated by turning the starting handle and so giving motion to a slide valve of peculiar construction, which, at its highest position, allows free communication between both hydraulic cylinders and the exhaust; a slight movement downwards connects the accumulator with the bottom of the piston of the small cylinder, which is of sufficient area to overcome the friction of the packing of both cylinders, and friction and inertia of levers, and thus the dies are brought quickly up to their work, whilst from the elevated exhaust cistern, water flows in behind the ram of the larger cylinder, thus effecting a material economy in the quantity of water required to be supplied under pressure.

The valve is next moved lower, allowing full accumulator pressure to come upon the larger ram, which in this particular machine transfers to the dies a pressure of 60 tons. After a slight pause, which is necessary to cool the rivet, the hand-wheel is reversed and the slide valve returned to its highest position, thus allowing the cylinders to empty themselves, whilst a constant pressure on the annular area of the small piston always draws the levers back, and the attendants make ready another rivet, and alter the position of the boiler shell under operation. The depth of gap is 5 ft. 3 in., which is found to be sufficient for ordinary boiler work, but this length can be increased. When not required for riveting, this machine is used for the purpose of bending or straightening ships' beams and girders whilst cold, an application of value. The straightening or bending jaws are placed midway between the centre and the riveting dies, and if necessary a pressure of 120 tons can thus be brought to bear upon a beam or girder placed between them. Moreover, they can be adjusted so as to take in any depth of beam, and as they do not interfere with the employment of the machine for riveting, they are as well fitted for occasional as for constant use.

MATERIALS OF CONSTRUCTION, STRENGTH OF.

The materials of which engineering constructions are made have had their properties made the subject of exhaustive research, but the introduction of new materials, or the advance in the manufacture of those which are already well established, demands constant and unremitting attention. As a constructive material, steel has made the most marked progress, and it is to be regretted that we have so few comprehensive accounts of its qualities. That of Daniel Adamson, of Manchester, read to the Iron and Steel Institute in 1878, from which we quote at length, is, however, a marked exception. Adamson remarks that numerous experiments have been conducted by several eminent engineers to prove the tensile strength of iron and steel, both in the shape of bars and plates. Unfortunately, however, many of the tests have been carried out with rude testing machines, rendering it difficult to obtain a true result of the endurance and strength of the metal under investigation.

In addition to this, a large proportion of the specimens tested have been of short lengths of metal, varying from 2 in. to 4 in., and in all such cases a higher tensile strain has been noted than can be depended upon in practice, while the elongation has also been much overstated, a large proportion of the extension of the specimens arising from a contraction of area, or breaking elongation.

With an accurate and sensitive testing machine, the maximum load is always carried in the mild ductile metals when about five-eighths of the elongation has taken place, the remainder, down to the point of breakage, is developed with a gradually reducing load.

Ordinary iron boiler-plates and hard steels are an exception to this law, and nearly universally break with a maximum load, but with little or no reduction of area.

Some experiments, conducted to determine the strength of steels with fixed proportions of carbon only, have been recorded by Vickers. Unfortunately, in this case, no cognizance was taken of other disturbing ingredients; but, as the tests in question were more especially to determine the strength of crucible steels, mostly used for tool-cutting purposes, they were of little value to the constructive or mechanical engineer to guide him in his practice.

Adamson states that having used, practically, a comparatively mild class of steels or ingot irons for twenty-one years, he has at times found from cold mechanical bending tests some irregularities in the working of such metals, which required a more careful investigation, both as regards composition, and the temperature at which they could be manipulated in the workshop and practically applied.

He therefore tested the endurance of iron and steel when subject to concussive force, such as can be produced by gun-cotton, gunpowder, or other explosive materials, partly with a view to understand what would be the effect on a steam boiler working under pressure, by the side of an exploding boiler, or the effect on a ship by collision with another, and whether wrought iron or steel possessed the greatest power to resist such accidentally produced force. The experiments were conducted by exploding gun-cotton 12 in. above a series of iron and steel plates, varying in thickness from $\frac{3}{8}$ to $\frac{7}{16}$ of an inch. The iron plates tested were of best quality, the steel plates of a mild class, suitable for boiler and shipbuilding purposes.

All the iron plates subject to explosive test were 18 in. square by $\frac{7}{16}$ in. thick, placed upon a cast-iron anvil block, about 20 in. square, having a segment of a sphere gouged out on the top side, 10 in. diameter and 4 in. deep. 12 in. above the plate 3 lb. of damp gun-cotton were fixed by a tripod of laths, attached to the cotton by two indiarubber rings. Again, upon this was placed 2 oz. of dry gun-cotton with a time fuse attached, to ensure a complete explosion of the damp compressed cotton.

On the gun-cotton exploding, the iron plate was entirely broken through 10 in. in diameter, and the centre piece forced down to the bottom of the anvil block, breaking up in an irregular line in the direction of the fibre, and to some extent across it.

The same experiment, precisely, was conducted on a steel boiler-plate, but only $\frac{3}{8}$ in. thick, which, after the explosion, with the same weight of gun-cotton, and under exactly similar arrangements, was depressed 3 in. into the recess of the anvil block without the slightest sign of fracture or any apparent injury whatever.

These experiments were repeated with the same result on five more best best iron, and five mild steel plates, the latter being both of the Bessemer and Martin-Siemens system of manufacture. So far these experiments were conclusive in favour of mild steel to resist violent concussive force.

With a view to get a full and more exact knowledge of the reasons why the iron plates broke up so much, as compared with the mild steels, a further series of thirty experiments were carried out, operating upon twenty-seven plates of varying quality, selected from the principal manufacturing districts; the iron plates of best and best best boiler quality from Staffordshire, Shropshire, and Yorkshire, including the Low Moor class; the steel plates both from the Bessemer and Martin-Siemens class of makers.

The composition of each plate is given in Table I. with figured references.

Table I.—Concussive Tests of Iron and Steel.

No. of Test.	Material.	Drifting after Annealing.		Chemical Composition.								
		From	To	Fe.	C.	Mn.	Si.	S.	P.	Cu.	O.	Cinder.
5, 6	Bessemer class of mild steel	·656	1·457	99·00	0·137	0·634	0·018	0·126	0·154	0·004	..	nil
7, 8	Special class Yorkshire iron	·687	1·3125	98·90	trace	0·18	0·13	nil	0·13	..	..	..
9, 10	Special class Lancashire iron	·687	1·3125	98·90	trace	0·14	0·14	trace	0·17	..	..	..
11, 12	Best best boiler-plate	·687	1·093	99·000	0·035	0·029	0·075	0·011	0·300	0·022	0·528	2·112
13, 14	Best best boiler-plate	·687	·968	99·000	0·040	0·029	0·094	0·011	0·306	0·024	0·496	1·984
15, 16	Martin-Siemens class of mild steel ..	·656	1·781	99·100	0·145	0·576	0·018	0·063	0·085	0·012	..	..
17, 18	Crucible steel	·656	1·625	99·00	0·16	0·61	0·04	0·08	0·04	..	..	..
19, 20	Bessemer class mild steel	·656	1·875	99·25	0·14	0·36	0·06	0·05	0·04	..	..	..
21, 22	Crucible steel	·656	1·531	99·00	0·13	0·77	0·02	0·11	0·04	..	..	..

The annealed mild steels again show a marked superiority of endurance, as will be seen on reference to Nos. 5 and 6, 15 and 16, and 19 and 20.

In the case of the first twenty-seven tests, the charge of gun-cotton was reduced to $1\frac{1}{2}$ lb., but being exploded 9 in. above the plate, instead of 12 in., as in the first tests. Attention may be further called to Nos. 15 and 19, as these plates at the first explosion were dished down into the anvil about $1\frac{3}{4}$ in., after which the plates were turned with the convex side up, and a further charge of $1\frac{1}{2}$ lb. of gun-cotton was exploded $7\frac{1}{4}$ in. above the crown of the plates, producing thereby a double corrugation without the plates exhibiting any outward sign of distress or injury. The mild steel thus showed powers of resisting concussive force, probably unequalled by any other metal that has ever been manufactured.

The two plates referred to had both been annealed previous to the first explosion, and the need of such annealing is illustrated by Nos. 17 and 18, which cracked and broke up by the explosion, the broken plate being forced down to the bottom of the dish in the anvil, although of a very good quality of mild steel.

The plate from its appearance had evidently been finished from the rolls at a low heat, and had a fine, smooth, oxide steel surface.

The necessity of annealing is further shown by the same class of plate, being of exactly the same quality, No. 21. This plate was experimented upon after being tempered in oil and afterwards annealed. The composition of this plate may be considered about the same as a great many Bessemer and Martin-Siemens mild steel plates.

The steel plate No. 5 was ruptured or split by the explosion. The cause of this was not known or understood until a full analysis was secured, when it was discovered that the plate in question contained about three times as much of sulphur and phosphorus, as is common to an average good Bessemer or Martin-Siemens mild steel boiler-plate. This experiment will probably explain why some breakages have occurred in the use of steel plates for boiler purposes, simply because the metal was of inferior quality, and establishes the need of a careful investigation into the character of the metal an engineer may select for practical purposes.

The classes of wrought-iron boiler-plates that broke up by the explosion, are represented by Nos. 11 to 14. Those that endured best by Nos. 7 to 10.

In these cases the sulphur is only a trace, while the plates have about the same measure of phosphorus that is contained in the other iron plates that broke up in every direction. The leading feature of the rupture of the iron plates, in the whole series of the experiments, may be said to closely follow in destruction, the quantity of sulphur, phosphorus, and cinder contained in the metal.

Further experiments were conducted with a view to test the iron and steel plates in question by drifting a washer cut from each plate. All the washers had a hole drilled in the centre, equal to the diameter of a rivet hole for the same thickness of plate, and with an outside diameter equal to the lap of such a plate for single-riveted joint.

The ordinary best best boiler-plates, of varying qualities, show an extension in the diameter of the whole, by drifting from 27 per cent. up to 50 per cent., while the best high-class Yorkshire plates endured drifting up to 91·5 per cent. before bursting.

Referring to the drift tests of the mild steel plates, the holes being $\frac{1}{32}$ smaller to begin with, or $\frac{5}{8}-\frac{1}{32}$, the outside diameter being proportionately less, agreeing with the thickness of the plates, the enlargement of the holes by drifting range from 133 per cent. to 187 per cent.

These drift tests further illustrate the necessity of annealing, as these proved plate No. 17 to be of a moderately good quality of metal, but before being annealed the explosive force broke it up.

The composition of the two mild steel plates that withstood the highest drift test, Nos. 15–20, both show a low measure of carbon, but No. 19 had slightly less phosphorus than No. 15, and only $\frac{1}{4}$ as much sulphur, thus, to some extent, explaining chemically that a higher endurance of drifting test is secured by the lowest measure of sulphur and phosphorus.

The indentation by the concussive force also showed that the corrugation is greater in No. 19 than in the plate, further proving it to be of rather milder quality, having slightly less carbon, less manganese, less phosphorus, and very considerably less sulphur. The only further reference, in the matter of drift tests, is No. 5; the increase of the diameter of the whole before bursting amounts only to 122·1 per cent. This plate having a larger measure of sulphur and phosphorus than the other steel plate, did not stretch as much by about 40 per cent. as the others of better and standard quality, and cracked by the explosion.

Innumerable records have been published giving the tensile strength of iron and steel; the quality, as a rule, has only been defined by the maker's name being attached to it, without any thought or care as to what the metal was composed of.

Great discrepancies have therefore arisen, and Kirkaldy, in his published records, 1862, gives a number of tests which were carried out by him between the years 1859 and 1861. It is stated that "the startling discrepancy between experiments made at the Royal Arsenal and by Kirkaldy is due to the difference in the shape of the respective specimens, and not to the difference in the two testing machines."

A record of the experiments here illustrated, Adamson contends, clearly disproves and sets aside this conclusion, whilst a fuller investigation of the constituent elements of the metal will plainly explain the difference that is reputed to have arisen, by the variation in the shape or sections of the specimens tested. This, however, is open to question.

The specimen 23. Table II., is a piece of mild steel boiler-plate of average good quality. This is borne out by the mechanical test, a permanent set being induced by a strain of 19·86 tons a sq. in., carrying a maximum load of 29·91 tons, with an elongation of 15 per cent., and ultimately broke down with 25·89 tons a sq. in., and a total elongation of 26 per cent. After the maximum load had been carried, the specimen began to reduce in sectional area about the middle for a distance of from 2 in. to 3 in., carrying less and less load as it elongated, until final destruction took place at about 26 tons. The carrying power is about the average of a very mild steel boiler-plate, and from the composition such a result might be expected.

The specimen No. 24, Table II., is taken to illustrate the carrying power of a plain rectangular section of steel boiler-plate, nearly a square inch in sectional area, but which is not of the highest quality, as indicated by the quantity of sulphur and phosphorus it contains, but to secure a standard force to break this class of metal, with irregular sections.

Nos. 25 and 26 are cut from the same plate, and are of the same composition, but planned out to produce a channel section, being increased or decreased in breadth to maintain the section equal to about 1 sq. in.

A series of tests were made with variable sections of this character, but practically no difference was found, after the maximum strain had been taken, arising from the difference in form, and this will be seen from specimens tested. No. 24 carried a maximum load of 27·72 tons, No. 25 carrying 27·7 tons, and No. 26 carried 27·8 tons a sq. in. These, together with more tests, on round, square, and rectangular bars, all show that variable sections do not alter the carrying power; the disturbing influence being entirely that of composition, coupled, no doubt, with more or less careful manipulation and work put upon the material. In making tensile tests of this character, short specimens of 27 in. to 4 in. are inadmissible, and at best misdirecting.

The mild steel specimen, No. 27 had its surface rough polished, over the 10 in. under test and divided off into ten equal parts. This test was carried on until the maximum strain was upon it, and by its elongation it showed itself to be of a very mild quality, requiring to induce permanent set 16·96 tons a sq. in., and carrying a maximum load of 27·67 tons, with a total elongation of 18·5 per cent. The load was then removed, leaving the plate unbroken.

The elongation of each separate inch was recorded, and it was found that the first inch elongated 14 per cent., the second inch 17 per cent., third inch 19 per cent., fourth inch 21 per cent., the fifth inch, arriving at the middle of the specimen, 23 per cent., the sixth 23 per cent., the seventh 20 per cent., the eighth 17 per cent., and the ninth 17 per cent., or the same as the second inch, while the tenth elongated 14 per cent., being the same comparative position as regards the ends as the first inch, and also the same elongation.

A similar plate, No. 28, and of the same composition, was next operated upon, the permanent set taking place with 16·96 tons, maximum endurance 27·45 tons a sq. in., with an elongation of 18·5, and being the same as the preceding test, within the most trivial fraction, the test was continued until the elongation reached 25 per cent., with a carrying load of 25·4 tons a sq. in.

It will be seen, by the test of an elastic sample of this character for a few inches, that a very large measure of the elongation is due after the maximum load has been carried, this being called the breaking elongation; while the power to carry an undue load is illustrated by the small elongation at the two end inches, as supported by the stronger portions of the specimen that are in the grip boxes of the testing machine.

TABLE II.—MECHANICAL TESTS OF IRON AND STEEL.

No. of Test	Material.	Size of Specimen.				Permanent set induced a sq. in.		Maximum strain a sq. in.		Elongation at Maximum strain.	Final Breaking strain on original area a sq. in.		Elongation.
		Length.	Breadth.	Thickness.	Area.								
		in.	in.	in.	in.	lb.	tons.	lb.	tons.	per cent.	lb.	tons.	per cent.
23	Steel ..	10	2·66	·375	1·0	44,500	19·86	67,000	29·91	15·0	58,000	25·89	26·0
24	Steel ..	10	2·0	·475	·95	43,684	19·5	62,105	27·72	19·0	52,105	23·25	24·0
25	Steel ..	10	Channelled		·91875	43,537	19·43	62,040	27·7	16·0	55,512	24·78	21·0
26	Steel ..	10	Channelled		·93125	45,106	20·13	62,281	27·8	17·5	55,302	24·68	24·0
27	Steel ..	10	2·35	·425	1·0	38,000	16·96	62,000	27·67	18·5	..	..	..
28	Steel ..	10	2·35	·425	1·0	38,000	16·96	61,500	27·45	18·5	57,000	25·4	25·0
29	Steel ..	8	2·66	·375	1·0	60,400	26·96	120,000	53·57	14·5	120,000	53·57	14·5
30	Iron ..	10	2·66	·375	1·0	37,500	16·74	57,000	25·4	14·0	57,000	25·4	18·0
31	Iron ..	10	2·35	·425	1·0	37,500	16·74	55,000	24·55	15·5	55,000	24·55	15·5
32	Iron ..	10	2·38	·42	1·0	35,481	15·84	45,696	20·4	5·75	45,696	20·4	5·75
34	Steel ..	Drilled		·4375	1·093	39,066	17·43	63,677	28·43	..	63,677	28·43	..
35	Steel ..	Punched		·4375	1·093	38,426	17·15	49,040	21·89	..	49,040	21·89	..
36	Steel ..	Punched and annealed		·375	·89	55,952	24·97	55,952	24·97	..	55,952	24·97	..
37	Steel ..	Punched		·375	·89	50,184	22·40	50,184	22·40	..	50,184	22·40	..
38	Bar iron	10	1	1	·7854	36,287	16·19	53,476	23·87	18·0	50,929	22·73	20·5
39	Bar iron	5	1	1	1·0	25,200	11·25	43,600	19·46	33·0	29,000	12·94	39·0
40	Bar iron	10	·90	·90	·810	27,777	12·3	44,074	19·64	20·0	29,753	13·27	23·5
41	Rivet steel	5	$\frac{11}{16}$ in. diam.		·3712	52,262	23·33	76,778	34·27	28·5	60,614	27·05	34·0
42	Rivet steel	5	,,	,,	·3712	53,340	23·81	78,394	34·99	18·5	53,906	24·06	33·5
43	Rivet iron	5	$\frac{7}{8}$ in.	,,	·6013	39,913	17·81	54,881	24·5	16·5	50,723	22·64	28·5
44	Rivet iron	5	,,	,,	·6013	39,913	17·81	56,544	25·24	18·5	49,890	22·27	33·0

No. 29, Tables II. and III., is a specimen of a much more highly carbonized steel, evidently well adapted for the bottom flanges of girders of bridges, or for suspension chains of bridges, as over several tests a noteworthy fact is that great uniformity has been proved.

The original area of the specimen being one square inch, permanent set was induced by 26·96 tons; it carried a maximum load of 53·57 tons, and elongated 14·5 per cent., being an elongation equal to the best boiler-plate iron, and carrying a load to induce permanent set, just about equal to the full carrying power of the best Yorkshire boiler-plates, thus showing that metal with about half per cent. of carbon, 1 per cent. of manganese, with a low measure of silicon, sulphur, and phosphorus, can be depended upon to carry double the load of the best wrought-iron plates that can be produced, and with as much dependence as regards elongation. In the drift test of the same specimen, being of the same proportion as those previously described, the hole increased 89 per cent. in diameter. The power of this metal to endure enlargement by drifting, may also be classified with that of the best iron boiler-plate; the steel withstood 89 per cent., as against 91½ per cent. of the drift test of the best Yorkshire boiler-plate of the same size and thickness.

No. 30 is a specimen of best Yorkshire boiler-plate; to induce permanent set it required 16·74 tons, carrying a maximum load of 25·4 tons, with an elongation of 14 per cent. maximum, and breaking load being the same. The ultimate stretch or elongation was 18 per cent., or 4 per cent. increase, after beginning to carry the maximum weight. This, like all other plate-iron specimens, broke under a maximum load, with a moderate elongation, and with no warning, as compared with mild steels.

The composition of this metal is stated on Table III., from which it will be seen to be a high-class iron, by the absence of sulphur, and the small measure of phoshorus, and it is supposed to contain only about 2·4 per cent. of cinder. This specimen was tested with the grain, or in the direction the plate had been rolled.

No. 31 illustrates a specimen of best boiler-plate, tested in the direction of the grain. The composition shows a small measure of carbon. Permanent set was induced by 16·74 tons; carried a maximum load of 24·55 tons, with an elongation of 15½ per cent., and then broke down suddenly with the full weight. No. 32 is a specimen of boiler-plate much used in Lancashire, that was tested with the grain. The composition shows the plate to be milder than the last, and it has a lower measure of alloying ingredients. Permanent set was induced by 15·84 tons; carried a maximum weight of 20·4 tons, with an elongation of 5·75 per cent.; on the load being continued a short while, the specimen broke suddenly without further elongation. This plate ought to have carried much more, had it not contained about 3·54 per cent. of cinder.

The specimen No. 34 was pulled asunder, having two drilled holes, and No. 35 is the same in every respect, except that it had punched holes.

The plate with drilled holes required to produce permanent set, through line of the holes, 17·43 tons a sq. in. of plate left; carried a maximum load of 28·43 tons, with an elongation in the hole of 56·66 per cent., breaking through without further change, with the full weight. The plate with the punched holes required to produce permanent set, 17·15 tons a sq. in., or about the same as the preceding one, but only carried a load of 21·89 tons, breaking suddenly through without warning, with a loss of 29·8 per cent. in strength, and of elongation of 33·33 per cent. through punching. This plate was not annealed after punching.

The drilled plates carry a somewhat higher tensile strain through the line of hole, as a rule, in proportion to the sectional area of the metal left, than a solid section of plate, no doubt, the circle of the holes, supporting the smallest section through their centre line.

Numerous experiments have been conducted with a view to ascertain the force required to punch holes through a given thickness of plate, but without taking cognizance of the quality of the metal.

To punch a hole through a steel plate, equal to a sectional inch of detruded area, may be found by multiplying the maximum tensile strength, a square inch, by 0·74, of the same metal, which will give the force required, the detruded area, meaning the circumference of the punch, multiplied by the thickness of the plate. This law may be depended upon both for the soft and the hard steels, and the total force to punch a hole through a hard plate, as compared with a soft one, may be said to accurately follow the law of its maximum tensile carrying power, so that a strong steel requires exactly a proportionate increase of force to punch a hole through a given thickness of plate, as it does to pull it asunder.

No. 38 represents a round bar of Cleveland iron, 1 in. diameter, length under test being 10 in. Permanent set was induced by 16·19 tons, carried a maximum load of 23·87 tons, with an elongation of 18 per cent., and finally broke down with 22·73 tons a sq. in., and a total elongation of 20·5 per cent. No. 39 is a specimen of an inch square bar, of a Lancashire iron made out of special brands of cast irons, carefully selected from English and foreign productions. The purity of this iron is remarkable, as shown by its analysis, whilst its mechanical behaviour was equally singular, only requiring to produce permanent set 11·25 tons; carried a maximum load of 19·46 tons, with an elongation of 33 per cent., and broke with a strain of only 12·94 tons a sq. in., and a total elongation of 39 per cent. This metal being singularly pure, further attention will be called to it, to show its great endurance over a large range of working temperature.

No. 40 is a specimen of Swedish bar iron tested over 10 in. in length, and lined off into separate inches, to further illustrate the peculiar behaviour of a ductile metal. Permanent set was produced by 12·3 tons a sq. in.; carried a maximum load of 19·64 tons, having then stretched 20 per cent., broke down with 13·27 tons, and a total elongation of 23·5 per cent. Had this bar been tested over a length of 2 in. only, the total elongation would most probably have been registered by the two middle inches where the bar pulled asunder, which stretched in themselves 46·25 per cent., while the two end inches only elongated 14·5 per cent., thus showing that the two middle inches stretched 31·75 per cent. more than the two end inches, and 22·75 per cent. more than the average of the whole 10 in. Besides, that an undue elongation must be recorded with a short specimen, it is more than probable that a much higher strain would have been carried before the maximum load was attained.

The 10-in. length was adopted by Adamson with a view to neutralize the extreme elongation caused by what is now pronounced as the breaking elongation, besides with a moderate length there is a greater probability of an accurate record being secured of the exact carrying power of the metal. The 10-in. length also gives facility for a simple division into one hundred parts, and by fixing a scale on the testing machine the elongation per cent. can be easily and accurately read off therefrom.

Nos. 41 and 42 are illustrations of $\frac{11}{16}$-in. mild steel bars largely used for rivets, and is of boiler-plate type of metal, but with more work put upon it to make into bars; No. 41 required 23·33 tons to produce permanent set, carried a maximum load of 34·27 tons, with an elongation of 28·5 per cent., finally breaking with 27·05 tons a sq. in., with a total elongation of 34 per cent. on the 10 in. length. No. 42 required 23·81 tons to induce permanent set, carried a maximum load of 34·99 tons, with an elongation of 18·5 per cent., breaking down with 24·06 tons, and having a total elongation of 33·5 per cent., showing a very great difference to exist in the powers of endurance between the carrying load of a mild steel and a comparatively pure wrought iron, yet the steel elongates nearly as much as the soft metal, illustrating in every way the greater powers of endurance of a mild cast steel or ingot iron over a puddled pure wrought-iron bar. Nos. 43 and 44 are specimens of $\frac{7}{8}$-in. round rivet iron, specially made. These were tested in the same way as the preceding. No. 43, requiring to produce permanent set 17·81 tons, carried a maximum load of 24·5 tons, with an elongation of 16·5 per cent., and a final breaking load of 22·64 tons a sq. in., with a total elongation of 28·5 per cent. No. 44 required 17·81 tons to produce permanent set, carried a maximum load of 25·24, with an elongation of 18·5 per cent. and a breaking load of 22·27 tons, the total elongation being 33 per cent.

These bars are shown to be comparatively high-class irons, possessing a moderately full tensile strength with great elongation and endurance, and such iron is a very safe metal for rivet purposes.

In attempting to weld steel boiler-plates, it is necessary to ascertain the composition of the metal before putting any labour upon it, and it is desirable that the carbon should not exceed $\frac{1}{8}$th of a per cent., while the sulphur and phosphorus should if possible be kept as low as ·04, silicon being admissible up to the extent of a $\frac{1}{10}$th of a per cent. Further experience is yet required to ascertain what exact composition gives the most satisfactory results by welding. At present some preference may be given to the Martin-Siemens class as compared with Bessemer metal, when both are of about the same chemical composition.

Few or no malleable metals, such as wrought iron or mild steels, can be found in the open market that possess a range of endurance at all varying temperatures, say from cold up to red heat, but nearly all ordinary bar or boiler iron and mild steels will endure considerable percussive force when cold, and up to 450° Fahr., after which, as the heat is increased, probably to near 700°, they are all more or less treacherous and liable to break up suddenly by percussive action. The poorer class of metals at this temperature, which may be called a colour heat, varying from a light straw to a purple and dark blue, are simply rotten. Some of these peculiar properties are illustrated by a series of tests of various qualities of metal.

TABLE III.—CHEMICAL COMPOSITION OF TEST PIECES, TABLE II.

No. of Test.	Material.	Fe.	C.	Mn.	Si.	S.	P.	Cu.	O.	Cinder.
23	Bessemer class of mild steel ..	99·3	0·13	0·468	0·023	0·031	0·037	..	..	..
24	” ” ” ..	99·057	0·082	0·68	0·005	0·100	0·056	0·02	..	..
25	” ” ” ..	99·057	0·082	0·68	0·005	0·100	0 056	0·02	..	..
26	” ” ” ..	99·057	0·082	0·68	0·005	0·100	0·056	0·02	..	..
27	Subcarbonized class of mild steel	99·397	0·180	0·284	0·042	0·007	0·090	..	..	..
28	” ” ” ..	99·397	0·180	0·284	0·042	0·007	0·090	..	..	..
29	Bessemer medium hard steel ..	98·4	0·410	1·080	0·055	0·031	0·051	trace	..	..
30	Special class Yorkshire iron	98·9	trace	0·18	0·13	nil	0·03	..	..	..
31	Best best boiler-plate	99·2	0·04	0·17	0·15	0·03	0·21	..	0·20	0·80
32	Best best Shropshire boiler-plate	98·8	0·045	0·086	0·186	0·012	0·208	0·005	0·658	2·63
34	Martin-Siemens class of mild steel	99·254	0·220	0·432	0·011	0·041	0·042	..	..	..
35	” ” ” ..	99·254	0·220	0·432	0·011	0·041	0·042	..	..	..
36	Bessemer class of mild steel ..	99·057	0·082	0·68	0·005	0·100	0·056	0·02	..	..
37	” ” ” ..	99·16	0·065	0·61	0·005	0·084	0·056	0·02	..	..
38	Cleveland bar iron	99·0	trace	trace	0·149	0·014	0·309	..	..	..
39	Special class bar iron	99·8	0·023	trace	0·037	0·013	0·033	0·003	0·091	..
40	Swedish bar iron	99·8	0·04	0·14	0·04	0·02	0·03	..	..	nil
41	Mild rivet steel	99·25	0·12	0·49	0·02	0·08	0·04	..	..	..
42	” ”	99·25	0·12	0·49	0·02	0·08	0·04	..	..	..
43	Special class rivet iron	99·49	trace	0·10	0·19	0·02	0·2	..	..	..
44	” ” ”	98·9	trace	0·125	0·196	trace	0·211	..	..	..

TABLE IV.—TEMPERATURE TESTS.

No. of Test.	Material.	Size of Specimen.				Permanent Set a Square Inch.		Maximum Strain a Square Inch.		Elongation at Maximum Strain.	Final Breaking Strain on Original Area a Square Inch.		Total Elongation.
		Length.	Breadth.	Thickness.	Area.								
		in.	in.	in.	in.	lb.	tons.	lb.	tons.	per cent.	lb.	tons.	per cent.
47	Bar iron	5	$1\frac{1}{8}$ diameter		·994	35,000	15·62	56,000	25·0	20·0	51,500	23·0	27·0
48	Steel ..	10	2·66	·375	1·0	36,500	16·29	62,000	27·67	19·0	52,500	23·43	30·0
49	” ..	10	2·06	·485	1·0	34,500	15 4	59,500	26·56	16·5	50,500	22·54	27·0
50	Bar iron	5	1	1	1·0	26,500	11·83	44,000	19·64	24·0	28,500	12·72	34·0

TABLE V.—CHEMICAL COMPOSITION OF TEST PIECES OF TABLE IV.

No. of Test.	Material.	Fe.	C.	Mn.	Si.	S.	P.	Cinder.
47	Best merchant iron	98·389	0·063	0·204	0·206	0·018	0·334	0·880
48	Subcarbonized class of mild steel ..	99·38	0·170	0·296	0·042	0·009	0·104	..
49	Martin-Siemens class of mild steel	99·224	0·200	0·500	0 009	0·035	0·032	..
50	Special class bar iron	99·8	0·023	Trace	0·037	0·013	0·033	..

The ordinary merchant iron, No. 47, shows that it may be bent cold or may be bent red-hot without signs of breakage or much distress. Nos. 47, 48, and 49 endure this bending test when cold and when red-hot, but at such a heat as can be induced by placing the metal into a bath of boiling tallow registering a temperature of about 610° Fahr., these metals break through by being bent, lose most of their malleability, and snap off short under the action of the hammer.

The same unfortunate element is exhibited by the mild class of Bessemer and Martin-Siemens steel, with this difference that they bend better cold, and more easily when hot, but both break up, by percussive action, at the medium temperature before named, the Martin-Siemens enduring somewhat better than the Bessemer class under these tests.

No. 48 is a mild Bessemer metal, and 49 a mild Martin-Siemens metal; 50 represents a very pure wrought iron.

All the mechanical properties of these metals and their chemical compositions are shown by

Tables IV. and V. It will be seen that the test No. 50, not only bent well cold and red-hot, but also at every intermediate heat at which the merchant iron and the mild steels failed.

Adamson is of opinion that no metal, containing much above a trace of sulphur, can endure bending at this colour heat, while, at the same time, the phosphorus must be low; in fact, such endurance can only be obtained by a comparatively pure iron unalloyed by other ingredients.

The mechanical power of No. 50 may again be referred to, that it only supported 11·83 tons to produce permanent set, carried the low maximum strain of 19·64 tons, but by this force it had elongated 24 per cent., yet ultimately stretched 34 per cent., and broke with 12·72 tons to the sectional inch of original area, clearly establishing that with a comparatively pure iron to secure great ductility and malleability we can only have a low carrying power. This is the same class of soft pure iron referred to when No. 39 was described.

The results, Table VI., were obtained by testing by corrosion three pieces of iron, and one medium hard, and one soft steel plate, in a water bath containing 1 per cent. of sulphuric acid, for a period of seventeen days.

TABLE VI.—CHEMICAL COMPOSITION OF CORROSIVE TESTS.

No. of Test.	Material.	Fe.	C.	Mn.	Si.	S.	P.	Cu.
53	Common iron	98·8	trace	trace	0·177	0·008	0·523	nil
54	Tudhoe crown iron	98·90	trace	trace	0·107	trace	0·217	ni
55	Tudhoe best best iron	99·00	trace	0·216	0·111	trace	0·165	nil
56	Medium hard steel	98·40	0·330	1·008	0·065	0·022	0·075	trace
57	Bessemer class of mild steel ..	99·354	0·115	0·504	0·055	0·028	0·037	trace
58	Pure iron	99·900	nil	nil	slight trace	slight trace	0·040	nil

The specimens subjected to test were 2 in. square by $\frac{3}{8}$ in. thick; the loss in weight by corrosion was recorded every twenty-four hours.

The common iron, No. 53, in seventeen days lost 79 per cent. of its total weight. Tudhoe Crown iron, one of the brands of the Weardale Iron and Coal Co.'s boiler-plates, No. 54, had a loss in the same time of 46·4 per cent. Tudhoe best best boiler-plate, No. 55, lost in seventeen days 34·7 per cent. The medium hard Bessemer No. 56 steel lost in seventeen days 13 per cent., while the soft Bessemer metal, No. 57, only lost 4·8 per cent. Attention may be called to the fact that the metals, according to the impurities of their composition, lost most in the least time.

On the second day the soft steel had lost considerably more weight than the hard steel, but at the end of the fourth day the hard and the soft steel had lost about equal degrees. From that period, however, on to the seventeenth day the soft steel, No. 57, did not lose as much as the hard metal by 8·2 per cent., and 74·2 per cent. less than the commonest iron in the same time.

In the diluted sulphuric acid bath the evidences are quite clear in favour of mild steel and the purest iron to resist corrosion, but before as much can be said as to the influence of sea or salt water, a more extended and careful series of experiments are required.

There can be no doubt that the medium hard class of steels, possessing double the strength of the best wrought iron that can be made, ought, without exception, to be applied to the purpose of bridge building and a variety of other similar structures. Up to this it has hardly found a place, and has had no consideration in proportion to its excellency and intrinsic value.

The strength of a wrought-iron plate is seriously reduced when pulled asunder across the fibre in proportion to the quantity of cinder it contains. This unfortunate principle does not so much apply to bar iron, as the mixed cinder is rolled into streaks or in parallel lines with the bar, only slightly disturbing the tensile strength of the iron when it is subject to a strain in one direction, hence a combination of good pig irons may be used and manufactured into plate iron, but the good material be spoiled by having too much cinder alone left in the iron, always robbing it of its strength and endurance in one direction to resist a working load.

Cinder as mechanically mixed with wrought iron can be well seen by planing and polishing the trod of a wrought-iron rail; the cinder is then shown to form disruptive lines in the direction of the length of the rail, and when put to work under a heavy rolling load, the iron breaks down laterally for want of cohesion, arising from an interposition of earthy matter.

The purity and superiority of a steel rail is made clear by subjecting it to the same treatment.

The test of the pure iron, Tables IV. and V., clearly indicates a low carrying power, but it is more than probable that such a metal, if worked down into thin plates, might be used in a large measure as a substitute for copper plates in the fire-boxes of locomotives.

Ordinary merchant or Staffordshire iron, or a Cleveland bar, although only possessing a very small power to resist percussive force at a colour heat, yet is much better adapted for the purpose of a chain cable or a rod to suspend a steady load, and though comparatively impure as iron, it possesses a much higher tensile strength than the purest wrought iron found.

The strong metals that will carry the highest tensile strain and possess great resisting power must be carefully treated in the manufacture, or the whole of its advantages may be turned to destruction.

The colour heat tests ought to be impressed upon all workmen to prevent the hammering of metals when half cold, or the heating of iron by red-hot iron for some final adjustment; where hammering is required it would be a better and wiser policy to only heat the iron with boiling water, or by applying steam against the surface a short time.

Finishing forgings or smith's work by hammering at a black heat at all times proves highly injurious, unless great care is afterwards used in annealing, and it is questionable then whether the full measure of strength of the metal in many cases is ultimately restored.

This dangerous temperature can also be produced by allowing engine fly-shafts, railway carriages, axles, and such articles to become hot, and boil off the grease or tallow, or for want of lubricants attain a temperature at which they are most liable to break down. In all such practical operations the work should be stopped and the metal left to cool.

In the case of steel fly-shafts, the cooling of a hot neck by water has a tendency to split the shaft in the journal and produce transverse cracks, so that when afterwards put to work these cause it to break down disastrously.

The strength of the purest iron, no doubt, is seriously interfered with at about 600° of heat F., and especially its power to resist percussive force, but in what way the cohesion of the particles are disorganized at a temperature midway between a cold bar and a moderate working red heat, may not be easy to describe. Such, however, being the fact, the greatest care should be exercised in all such ordinary practical operations.

In dealing with certain matters affecting the use of steel, E. Marché, of Paris, remarks in the Journal of the Iron and Steel Institute, 1878, that, with the exception of carbon, the other substances, such as manganese, phosphorus, and silica, do not afford us, despite all the experiments made, any exact notion as to their respective action on some of the properties of steel. Moreover, and with reference to the determination of the conditions under which the experiments should be conducted, there still prevails the greatest uncertainty, on account of the difficulty of establishing exactly the relation between the results of, for example, a traction experiment and the effects produced on the same metal by flexion, tension, or concussion.

If, when grouping together the thousands of experiments made in various countries by different experimentalists, and on steel produced in various works, it has been hitherto impossible to attain to any confirmation of the laws connecting the physical properties of steel, and admitted in the classification of the establishments or works producing that article, laws, however, which many consider as having been prematurely admitted, that impossibility may be chiefly attributed to the fact that those experiments do not allow of any direct comparison, and that, previous to an analysis of those results, it would be necessary to make some corrections, in order to eliminate the complicated causes which affect them, the experiments not having been conducted under strictly analogous conditions.

The results of the experiments of natural philosophers, say in regard to density, are referred, by way of correction, to a like atmospheric pressure and to a like temperature; but all those experiments should be referred to a similar form and size of sample, to a similar degree of elaboration of the metal, to a similar molecular condition, and the like.

It must be admitted, however, that those corrections are very difficult to make, and that, in every point of view, it would be preferable to bring about a general understanding between the experimentalists, as to the conditions of conducting everywhere experiments capable of undergoing a direct comparison.

The first difficulty met with in endeavouring to compare the experiments made in different countries, is the varying systems of measurement.

When one has to proceed to the investigation of the physical properties of pieces or samples of steel handed to an experimentalist, it would be necessary for him to know, in the first instance, in order to determine the nature of the experiments to which those pieces or samples are to be subjected, whether the object in view is to study the nature and general qualities of the steel *per se*, or to ascertain how it would act under certain given applications.

In the former case, it would be always necessary to test previously by traction the cylindrical or rectangular bars of the section and length to be determined on.

In the latter case, the system of experiments would depend on the nature of the application itself, and, generally speaking, the flexion and the "shock" (concussion) at the flexion will form the most useful tests.

We shall commence by examining the conditions relative to the traction experiments.

In subjecting to a tensile strain a steel bar of given section ⊓ and of length l, the facts to be observed and the quantities to be determined—if a complete experiment is to be made—should be the following:—During the period of perfect elasticity, the observation of the momentary elongations under given loads will allow us to determine the co-efficient of the modulus of elasticity, E. When the elongations cease to be in proportion to the loads, then the limit of elasticity is attained, load per unity of section, beyond which permanent elongations are produced, L. The charge or load is increased until the rupture is produced, under a charge for each unit of section, R. The two portions of the broken rod are brought together, and the total length is then measured, deducting therefrom the original length; the final elongation at the rupture is then ascertained, and it is generally expressed with regard to the original length by per cent., Δ. Then measure also the section taken by the rod at the point where the rupture has occurred. The difference between the original section and the ruptured section is called by Kirkcaldy the contraction, expressed in so much per cent. of the original section, but we prefer explaining this phenomenon of the contraction of the rupture section by the relation which the contracted section bears to the original section —that is *striction*, Σ. By dividing the total charge which produced the rupture, not by the primitive section, but by the contracted section, we have the resistance for each unit of section broken, F. If, in a great number of trials, we are content to determine the diverse quantities above mentioned, it is nevertheless necessary, in order to have an exact and complete knowledge of the nature of any steel, to observe, in addition thereto, the permanent successive elongations made by the bar under trial, under increasing charges, from the one corresponding to the limit of elasticity to the charge of rupture or breaking load.

The manner in which these elongations vary, with the excess of charge on the limit of elasticity, is ordinarily represented by the aid of a graphic diagram, which gives the curve of the elongations and allows of the measurement being made of the work of resistance to the rupture, of which we shall speak hereafter. Finally, it is useful, in order that the test may be complete, to describe the exact form which the bar presented after the rupture, so as to observe how the elongation was divided, and what is the exact position of the rupture section.

Coefficient or Modulus of Elasticity, E.—The modulus of elasticity is the relation of the charge to the elongations produced during the period of perfect elasticity. It is constant during that period. In France that relation is expressed in kilogrammes to the sectional square metre, and in England in pounds on the square inch.

The investigation of this coefficient of elasticity for castings, iron and steel, has given rise to numerous experiments, and the figures which have been arrived at are so unlike that they cannot be brought together and compared, in order to ascertain whether, in the special point of view which we are now taking up, namely, the properties of commercial steel, we could account for the influence of the composition and of the purity of those steels by the manner in which they act during the period of perfect elasticity.

The modulus of elasticity is generally admitted at—

For castings	10,000,000,000
,, iron	20,000,000,000
,, steel	20,000,000,000

According to Redtenbacher it varies—

In iron from	14,954,000,000 to	24,988,000,000
,, steel ,,	20,020,000,000 ,,	23,975,000,000

According to Reuleaux—

Iron in the form of bars or wires	20,020,000,000
,, in thin plates	24,010,000,000
Cast iron	30,005,000,000
Other kinds of steel	20,020,000,000

According to Kupffer—

Flat iron, in the sense of rolling	17,622,000,000
,, in a transverse sense	19,146,000,000
,, English rolled	20,010,000,000
,, ,, forged	20,232,000,000
,, Swedish	21,341,000,000
Soft cast steel	21,330,000,000
Reimscheid steel	21,101,000,000

Rosset resumes, as follows, the numerous experiments made by him on the materials used in the manufacture of cannon—

Castings, cannon	14,354,000,000
Iron hoop, grained, Peter Gaudet	20,000,000,000
,, steeled	20,934,000.000
Krupp steel, natural state	19,700,000,000
,, ,, tempered in oil	20,714,000,000
,, cannon steel	20,969,000,000

We now give the value of the modulus of elasticity resulting from the traction trials made by Knut Styffe—

	Tenour of Carbon. Per Cent.		
Bessemer forged steel of Högbo	1·26	21,177,000,000	Medium 22,255,000,000
,, ,,	1·05	21,515,000,000	
,, ,,	0·1	22,721,000,000	
,, ,,	0·15	24,072,000,000	
Wikmanshyttan ,,	1·22	21,949,000,000	
Krupp ,,	0·61	22,046,000,000	
Puddled rolled steel of Surahammar	0·56	21,033,000,000	
Lowmoor puddled iron	0·20	22,480,000,000	20,677,000,000
Dudley ,,	0·09	19,972,000,000	
,, ,,	0·09	19,296,000,000	
Motala ,,	0·05	21,274,000,000	
,, ,,	0·20	20,791,000,000	
Surahammar ,,	0·14	21,853,000,000	
,, ,,	0·20	21,418,000,000	
Aryd rolled iron	0·07 to 0·08	18,813,000,000	
,, ,,	0·07 ,, 0·08	19,537,000,000	
Hollstahammer rolled iron	0·07	20,357,000,000	
,, ,,	0·07	21,660,000,000	

These trials already show us that the influence of the quantity of carbon is nil in the elastic elongations produced by the same changes or loads; the coefficient of elasticity of steels containing more than 1 per cent. of carbon is not superior to that of the irons of Motala, Surahammar, and others, which only contain 0·07 to 0·2.

When it is proved, on the other hand, that the least variations of the quantity of carbon completely modify the data of the permanent deformation, one cannot but be struck with the fact that during the period of perfect elasticity, the momentary elongations are independent of the nature of the metal. They appear to be modified only by the purity of the metal, and by the degree of work to which it has been subjected.

The trials or tests of Bauschinger on a series of Ternitz steels are more conclusive in that respect, because they have been made on products of the same origin, only differing with regard to the quantity of carbon, and tested under the same form.

On the tensile test, Table VII., those steels, of which the quantity of carbon varied from 0·14 to 0·96, gave;—

TABLE VII.—TENSILE TESTS OF STEEL.

Quantity of Carbon.	Limit of Elasticity a MM.	Coefficient of Elasticity. E
	K.	
0·14	29·50	22,550,000,000
0·19	33·10	21,700,000,000
0·46	34·50	22,550,000,000
0·51	34·05	22,100,000,000
0·54	34·90	21,550,000,000
0·55	33·00	22,200,000,000
0·57	33·10	21,600,000,000
0·66	37·45	22,450,000,000
0·78	37·50	24,700,000,000
0·80	40·05	21,500,000,000
0·87	42·90	21,850,000,000
0·96	48·70	21,750,000,000
	General average	22,200,000,000

The experiments made at Woolwich in 1870, by a committee of civil engineers, resulted, for steels of various works, in the limit of elasticity varying from 26 to 42 kilos. and the quantity of carbon of 0·30 to 0·90 per cent., an average coefficient of 20,627,000,000, the minimum being 20,160 and the maximum 21,060,000,000. Some irons tried under the same conditions gave 20,092,000,000.

From all those results, one may conclude that the coefficient of elasticity of steel, whatever may be its hardness, varies only from 20 to 22,000,000,000.

Looking at these tests in a practical point of view, we may come to the conclusion in regard to the results, that although in some particular cases, for example, in investigating the action of manganese and phosphorus, it would not be unimportant to deduce some facts relative to the modulus of elasticity; nevertheless that part of the tension tests may be in general dispensed with, as being the most delicate, the longest in duration, and, on account of the great lengths of rod or bar required, the most expensive. Consequently, the experiments may be made on short lengths, and a larger number of tests obtained, with the same quantity of steel, within the like given time and at the like expense.

The experiments made by Bauschinger on the steels of the Reschitza Works, Hungary, demonstrate how much attention and time would have to be devoted for determining certain points, which after all throw no fresh light on the properties of the steel subjected to the experiments in question, inasmuch as with respect to all those steels, differing considerably as they do in regard to the quantity of carbon, the modulus of elasticity is comprised between 22,400,000,000 and 23,000,000,000.

We may at once state that Bauschinger's experiments on the Ternitz, as well as on the Reschitza steels, demonstrate likewise that the modulus of elasticity is the same, whatever may be the hardness of the steel, at compression and flexion, and that it is represented by the same figure as the coefficient of elasticity at the tension test.

Limit of Elasticity of Steel.—If, during the period of perfect elasticity, the elongations are in proportion to the loads or charges, and disappear with the action of those loads, the limit of elasticity is the equivalent of the last charge producing that effect; and under a heavier load than that limit of elasticity there is a permanent elongation.

But if there be a concordance of opinion with respect to the existence and definition of that limit of elasticity, it is otherwise with regard to the fixing of its value, for, however exact and correct the instruments employed, it is difficult to determine the precise moment at which the state of perfect elasticity passes to that of permanent deformation. More correctly speaking, the precise moment in question does not exist with reference to experiments on steel rods, because, in point of fact, there is a period of break of elasticity, during which certain portions of the rod or bar undergo permanent elongations, whilst other portions resume their original length.

On account of the uncertainty attending the phenomenon, it is necessary to establish conventional rules for determining the limit of elasticity, and as those vary which are adopted by the various experimentalists, it results that the limit of elasticity observed in respect of the same kind of bar of the same length, say in England and in Sweden, will not be the same.

It is true that Wertheim and other experimenters agree in considering, as the limit of elasticity, the load or charge that produces a permanent elongation, equal to the 0·00005 of the original length, in other words, and with reference to a bar or rod of 1 metre, a permanent elongation of five hundredths of a millimetre; but, on the other hand, so feeble an elongation is considered, by many experimenters, as the possible effect of accessory causes, and they are of opinion that we cannot admit that the limit of elasticity is exceeded until such time as a more clearly defined permanent deformation is observable, and the extension under heavier loads testifies to the reality of the phenomenon.

These considerations have led to the following special definition by Styffe;—

"If an iron or steel bar be gradually extended by successive loads, which at first are so small that they occasion no permanent elongation, but are gradually increased, and are always allowed to operate for as many minutes as each additional weight is per cent. of the entire load, then the author regards as the limit of elasticity that load by which, when it has been operating by successive small increments as above described, there is produced an increase in the permanent elongation which bears a ratio to the length of the bar equal to 0·01, or approximates most nearly to 0·01, of the ratio which the increment of weight bears to the total load."

Styffe adheres to the opinion that the limit of elasticity cannot be considered to be attained until we can ascertain exactly and measure the determined increments of the permanent elongation; he furnishes some estimates of the limits of elasticity considerably higher than those given in Wertheim's definition.

The following are a few examples, Table VIII, taken from the tabular data of Styffe;—

TABLE VIII.—LIMIT OF ELASTICITY.

Material.	Limit of Elasticity.	
	According to the definition of Wertheim.	According to the definition of Styffe.
	K.	K.
Puddled iron of Motala	under 16·7	20·8
" "	" 15·8	21·0
" "	14·5	18·8
" "	" 15·3	18·8
Puddled iron of Middlesbrough-on-Tees	20·0	22·6
" "	" 19·3	21·2
" "	20·5	23·5
" "	24·1	24·8
Puddled iron of Dudley	" 16·5	19·9
" "	" 16·8	20·0
Cast steel of Wikmanshyttan (carbon 1·22 per cent.)..	about 28·9	51·3
" "	" 28·9	51·1

The difference is from 3 to 4 kilos. in irons, and amounts to 22 kilos. in the very hard steel of Wikmanshyttan.

These figures show the necessity which exists of arriving at a mutual agreement as to the fixation of the limit of elasticity, and how imperative it is, in all cases, that, in the publication of the series of trials, the method of estimating that useful value should be pointed out.

The value of the limit of elasticity is, in point of fact, the primary manifestation of the degree of hardness or of malleability of a steel, and in many cases the basis of calculation of the dimensions of the pieces.

As, moreover, we have seen that tests on short bars are to be preferred, and that on short bars the definition of Wertheim cannot be applied, whilst, on the other hand, the definition of Styffe appears to give too high a quotation of figures, one can see what interest would be attached to a plain agreement on the subject, easily formed and adapted to the tests of short bars. If all the tests were made on bars of the same section and of the same length, 0·15 or 0·20, for example, they could be proceeded with as follows;—Increase the charges until a permanent measurable elongation is produced, one-tenth of a millimetre at least, then increase the load by a fixed quantity representing 1 or 2 kilos. per square millimetre; observe a second permanent elongation, and infer therefrom the value of the limit of elasticity by admitting that the two elongations are in proportion to the excess of the charges or loads on that limit of elasticity. If P is the charge which produces the first elongation i, and i' is the second elongation produced by the charge P′, we have

$$\frac{i}{i'} = \frac{P - L}{P' - L} \text{ whence } L = \frac{Pi' - P'i}{i' - i}.$$

Resistance and Elongation.—These two qualities are determined in all the experiments; they serve as a basis for the classification of the works; and it is generally admitted that a steel is defined by the two values, R and Δ, of the resistance to fracture a square millimetre of the sectional area, and of permanent elongation on fracture expressed in hundredths of the original length of the broken rod.

But, in order that this definition may be absolutely correct, so that one can find, in the ratio of the two characteristic values, resistance and elongation, the elements of a rational appreciation of the nature and quality of a steel, it is indispensable that the value of Δ result from the testing of bars identically alike as regards section, form, and length.

It is found in every series of experiments made upon steels of variable hardness that the two values of R and Δ vary inversely, the elongation diminishing as the resistance increases, and that it is possible, in presence of tests carried out on steels of the same origin, to find a simple and sufficiently approximate relation between these two qualities.

When it is desired to represent this relation with the aid of a curve, taking the resistances as abscissa and the values of Δ as ordinates, lines are obtained which differ but slightly from straight lines, inclined to the axis of x's in the ratio of 1 to 2, so as to afford the general relation.

$$R + 2\Delta = \text{a constant } a.$$

But it is easy to prove that for the same steels the value a of the sum $R + 2\Delta$ will not be the same if the tests be carried out upon samples of different form and length.

It is well known that the elongation on fracture Δ, which is the ratio of the elongation produced to the original length, is so much greater as the rod is shorter, on account of this well-known fact, that the different parts of a rod are not elongated equally when permanent deformation takes place; that the portions near the points of attachment become less elongated, and that the region in which fracture takes place, accompanied by a reduction, more or less appreciable, of the cross-section, is subject, on the contrary, to an elongation much greater than the mean elongation.

But if the necessity of adopting one and the same length for the test bars is acknowledged by all experimenters, no uniform opinion has hitherto prevailed as to the choice of this length, each one proposing the adoption of the type which he has hitherto employed.

On the other hand, we think that the importance has not been sufficiently insisted upon, not only of measuring the elongation of rods of the same length, but also on bars of the same form and section. In a word, the tests must be carried out, if not on pieces identically alike, at any rate on such as are similar in the mathematical sense of this word.

If this condition had been fulfilled in the numerous experiments published, we should certainly be in a position, on analyzing the variations of the value $R + 2\Delta$, to form an exact appreciation of the effects certainly produced on the relations between the resistance and the elongation, by the mechanical strain undergone by the metal during manufacture, and the presence in the steel of other elements than carbon.

The carbon increases the resistance and diminishes the elongation; this is a proved and uncontested fact; but it is questionable if the other elements, as manganese, phosphorus, chrome, do not act in a similar manner. The manganese increases the resistance and diminishes the elongation, just in the same way as the carbon, but in quite a different measure. The chrome increases the resistance, but without reducing the elongation. Forging, rolling, annealing also exercise a different action, and are to be determined.

But it is necessary that all the tests be carried out on bars of the same section and the same length in order that the elongations have the same comparative character as the resistances, and that the value of the sum $R + 2\Delta$, be the representation in figures of the effects of the working and of the chemical composition of the steels.

Thus, the values shown in the classification of Creusôt for the resistance of the elongation on fracture, gives the relations;—

$$\text{For the ordinary quality, } R + 2\Delta = 104 \qquad (1)$$
$$\text{For the superior quality, } R + 2\Delta = 107.$$

The tests being applied to two bars of 16 mm. diameter and 0 m. 100 long. R being expressed in kilos. a square mm. of section, and Δ in a percentage of the original length.

One would conclude from these two relations that the sum $R + 2\Delta$ was so much higher as the purity of the metal was greater, so that if two steels, tested under the same conditions of dimension of bar, gave a relation $R + 2\Delta < 104$, it would be admitted that they belong to a series of steels less pure than those of the ordinary quality of the Creusôt classification.

The classification of the Société John Cockerill, at Seraing, furnishes for tests on rods 0 m. 100 long and 15 mm. diameter the relations $R + 2\Delta = 100$.

That of the Terre-Noire Works Company gives;—

$$R + 2\Delta = 92;$$

but the tests are made on rods of 20 mm. diameter and 0 m. 200 long.

The experiments of Bauschinger on the Ternitz steels give the average relation—

$$R + 2\Delta = 89.$$

This corresponds to the result obtained on bars of rectangular section, 70 by 12 mm., with a length of 0 m. 400.

The table of tests by traction on steels with a variable quantity of carbon made at the Terre-Noire Works gives—

When the tests are applied to small bars of 14 mm. diameter and 0 m. 100 long—

$$R + 2\Delta = 97{\cdot}5. \qquad (1)$$

When they are applied to bars of 20 mm. diameter and 0 m. 200 long—

$$R + 2\Delta = 94{\cdot}5; \qquad (2)$$

and when applied to bars similar, but the elongation being measured on 0 m. 100 only

$$R + 2\Delta = 101. \qquad (3)$$

These three relations show well the effects of a difference of form and dimension of the test bars. The 1st and the 3rd relations give the measure of the influence of the points of attachment of the rods which reduces the elongation.

The test carried out on the steels with variable quantity of manganese give respectively, under the same conditions of diameter and length of the bars, the three relations—

$$R + 2\Delta = 108 \qquad (1)$$
$$R + 2\Delta = 106 \qquad (2)$$
$$R + 2\Delta = 114. \qquad (3)$$

Lastly, those on the steels having a variable quantity of phosphorus give respectively—

$$R + 2\Delta = 106 \qquad (1)$$
$$R + 2\Delta = 105 \qquad (2)$$
$$R + 2\Delta = 113. \qquad (3)$$

On comparing the tests of those relations which correspond to the same dimensions of bar, it will be seen that the presence of other substances than the carbon, show themselves by an important modification of the ratio of the load to the elongation.

The dimensions which appear to be the best for tension tests, from all points of view, for rods of circular section, are a diameter of 20 mm. and a length of 0 m. 200.

The adoption of this type would not exclude the use of rods of different lengths, on the express condition that the diameter should be always equal, as in the type, to the tenth part of the length. That is to say, that the value of Δ should be the same with rods of

15 mm. diameter and 0 m. 150 long.
18 ,, ,, 0 m. 180 ,,
20 ,, ,, 0 m. 200 ,,
25 ,, ,, 0 m. 250 ,,

With regard to the testing of plates, which possesses great interest at the present time, a typical length of 0 m. 200 should be adopted, but there is reason to undertake a special research for fixing the width of the bars in relation to their thickness, so that the elongations produced be always the same as those produced by round rods of 20 mm. diameter. A series of special tests undertaken with this object, would readily give the elements of understanding to be arrived at on this point.

Striction and Resistance to each Unit of Sectional Area Fractured.—The permanent elongation of the bars brings about a reduction of the sectional area, and the rod no longer preserves the cylindrical form, a drawing down takes place in the portion fractured at a point where the sectional area becomes only a fraction of the original sectional area; this section of fracture is so much the less as the rod is more elongated, drawn out, and in proportion to the softness of the steel.

D. Kirkaldy was the first to insist on the fact of the contraction of the sectional area at the point of fracture, and he has regarded its amount as an excellent measure of the hardness of steel.

It is, in fact, an element less dependent on the length of the rod than the final elongation.

But it is advisable to note that the values determined practically are often of a very irregular character, resulting from the fact that the special circumstances of the experiment, the presence of local defects, for instance, exert a considerable influence over the place occupied by the section of fracture on the length of the rod.

Theoretically, in fact, and in the case of absolute homogeneity in a metal, fracture should take place in the middle of a rod. If the fracture takes place at another point, or especially at a point near the attachments, the final elongation, the drawing out of the region of fracture, does not take place under normal conditions, and the striction has a higher value.

In order to obviate this difficulty, and to ensure, by the exact estimation of the striction, a useful element of the hardness of the steel, it will be well to set aside all those tests in which fracture takes place near the points of attachment, and it would be useful in the publication of series of tests to always indicate the exact position of the section of fracture with reference to the middle of the rod.

As to the final resistance to fracture, F, this value is subject to the same uncertainty as those of the striction from which it is obtained; it can, therefore, only give rise to useful comparisons under the same reserves.

This value, in all cases, would appear to decrease in inverse proportion to the hardness of the steel, its percentage of carbon, and its strength a unit of original sectional area.

Under the action of the intermediate loads to which a rod is submitted, from that which corresponds to the limit of elasticity to that of fracture, a series of permanent elongations takes place, increasing from O to Δ, according to a law the observation of which, often neglected in tests, appears to be nevertheless of capital interest in a study of the properties of steel, and especially of soft steels.

The register of successive elongations, and the diagram which represents the law of their increase with reference to the loads, is then an indispensable complement to every traction test.

Many experimenters take care to represent by comparative figures the faculty of elongation of the steel during the period of permanent deformation.

It is the most usual practice to give the value of elongation corresponding to the same load superior to the limit of elasticity.

It is thus that, in the table of tests on phosphorus steels, compiled by Thurston and communicated in the paper of Holley, read at the Inst. of C. E. in 1878, appears the elongation produced by a constant strain of 42 kilo. a sq. mm.

The inconvenience of this method is, that it cannot be applied to an extended series of steels comprising very soft and very hard varieties, for the load to be considered should be at the same time superior to the limit of the elasticity of the hardest steel, and inferior to the resistance of the softest, which it is often impossible to realize.

Moreover, it is well known that during a tolerably long range, from the load corresponding to the limit of elasticity to a load equal to about three-fourths of the breaking strain, the elongations produced increase with tolerable regularity, and proportionately, not to the loads, but to the excess of the loads over the limit of elasticity.

Comparative results would then be obtained, on measuring the elongation produced under a load always exceeding the limit of elasticity of the same quantity.

If L be the limit of elasticity, and if observations be made, for a whole series of steels, of the elongations, i, corresponding to a load $L + pp$, being a constant quantity, the different values of i will well represent the faculty of permanent elongation of the steels considered during the period of regular deformation.

If, besides, one calculates the ratio $\frac{p}{i}$ of the excess of the load over the limit of elasticity at the corresponding permanent elongation, at say $\frac{p}{i} = D$, this quantity will represent what may be called the modulus of permanent deformation, which permits of estimating the elongation produced under any given load, inferior, however, to that under which the accelerated deformation commences, which is manifested by the special attenuation of the portion of the rod where the fracture is about to take place.

The value of this coefficient D, characterizes very clearly the nature and the degree of hardness of a steel, and permits of combining the effects of deflection with those of tension.

The value of D, expressed in kilos. a square metre as the modulus of elasticity E, increases with the hardness of the steels; it is about 250,000,000 for extra soft steels, with a tenour of carbon from 0·1 to 0·15 per cent., or for very pure Swedish irons, 1,500,000,000 for very hard steels at 1 per cent. of carbon.

There remains to notice the resistance of steels to tensile strain, represented by the elastic effort by the half product of the load corresponding to the limit of elasticity and of the corresponding elastic elongation and the effort of fracture by the area of the diagram obtained by registering the successive permanent elongations.

But this estimation does not supply a comparative value of steels as regards resistance to impact, tests with a falling weight having always been applied to bending, and the impact producing in this case has a considerable effect out of proportion to those with a tensile strain.

It may be stated here, that the steels containing a certain quantity of phosphorus show, on tensile tests being applied, resistance and elongation but little differing from those of steels without phosphorus, but with the same quantity of carbon or manganese, in order that the quantity representing the resistance to tensile strains be appreciably the same in the two cases, and yet on proceeding with impact tests by deflexion, these differences are found considerable.

When it is required to examine and receive some pieces of steel, it is on these pieces themselves that the tests are carried out, with the intention of ascertaining how they behave under the action of the strains to which they will be subjected in practice, and in this case it is generally to tests of deflexion, and especially to deflexion by impact, that they are subjected.

We now possess, thanks to the numerous researches referred to, many of the elements enabling us to deal with the theory of permanent deflexion and of impact tests, but this theory can only be established with complete exactitude by new tensile tests, more methodical and absolutely uniform in character, to confirm and complete the data hitherto furnished.

The same may be said of the classification of the products, so various and so numerous, designated by the name of manganese, phosphorus, chrome, silicium, and tungsten steels, which would only be possible when we have the knowledge of all the physical properties which show themselves in the tensile test, assigning to each one of these products its exact place in the general scale of steels.

Strength and Resistance of Materials.—The theory of the strength and resistance of materials is closely connected with that of molecular mechanics. The latter science, however, is much more extensive, and affects many other problems than those of the practical engineer; it has been the subject of learned researches, often difficult to understand, and still more to analyze or criticize in a memoir of limited extent. Moreover, the strength of materials being a branch altogether of practical application, requires only to borrow from scientific theories the principles on which to base rules of construction, simple enough to be of general application, and yet sufficiently exact to be used with confidence. The succeeding view of our present state of knowledge of this subject is due to Jules Gaudard, and was first presented to the Inst. of C. E. in 1869 by W. Pole.

The formulæ of strength bring into view, on the one hand, the destructive action of external forces, and, on the other hand, the resisting molecular actions of the material.

External forces are of two kinds; one kind comprises elements directly given, such, for example, as weights; the other kind consists of reactions, functions of given forces. In certain cases these reactions may easily be found by the science of statics alone, as, for example, in the case of a beam placed on two supports. In other cases they will depend on the changes of form of the solid; it is this, for example, which causes the difficulty of calculation in arches and in continuous beams of several spans. Or, lastly, it may happen that the body in question may not be in a state of equilibrium, but that its particles may oscillate under variable dynamic influences or forces of inertia; this is the case of concussions, vibrations, and the like.

These various external forces being determined, it will easily be seen whether they tend to cause certain parts of the solid to elongate, or to shorten, or to shear, or to turn round certain axes. These various effects, extension, compression, sliding, torsion, flexure, may further manifest themselves separately or may combine with each other.

Under the action of these forces, the body will necessarily be changed in form; for solids perfectly rigid are only pure abstractions. The study of these changes of form constitutes the object of the theory of elasticity. The study of strength or resistance has to do with the power which the solid, according to its physical constitution, possesses to maintain, if not its form, at least the cohesion of its parts.

For the constructive engineer the question of resistance to rupture is of capital importance. The elastic change of form interests him less directly, because he knows beforehand that this change is generally very small, and presents no great inconvenience. It often happens, however, that the two questions are connected together; for example, in the case already cited, where the change of form of the body influences the reaction which it receives from its external supports. It may happen, also, that a change of form may present in itself a direct practical interest; thus in the testing of a bridge, if the observed deflection agrees with that predicted by the calculation of the elasticity, it will be inferred that the beams do not possess any hidden defect capable of producing an abnormal deflection. The changes of form may also exert a notable influence on the strength of constructions where different materials are combined together.

Extension.—Molecular action is a force internal, or reciprocal, which opposes indefinitely the approximation of two particles, but only opposes their separation up to a certain limit. This limit being attained, the two particles find themselves suddenly withdrawn from their sphere of mutual action, and rupture takes place.

According to this idea, a fibre or thread of particles being subjected to tension, the force producing rupture may be measured, and this force will vary with the substance. In this elementary case, so simple in appearance, the question arises, whether a particle extends its attractive action beyond the particle immediately adjoining it on either side? If this were so there would be differences of condition between the ends and the middle of the fibre, and we ought to be able to designate beforehand the points of rupture. But we do not know that these points are determined by any other laws than the mere caprice of the specimen, and we assume that, for a thread of an absolutely theoretical regularity, the rupture may take place at every point at the same instant.

If we take a material rod of finite thickness, the phenomenon becomes more complicated; for the particles now undergo displacements, not only longitudinally but also transversely. This is very obvious with a viscous matter, which diminishes in thickness as it is increased in length; but as everything is continuous in nature, viscous or pasty matters of all degrees mark the transition from liquids to solids, and these latter ought to preserve in a faint degree the same physical properties. This is, moreover, a fact which the experiments of Tresca, upon the flow of solids, have shown in a striking manner.

Here we already find ourselves in the presence of an obscure phenomenon of molecular mechanics. In considering, however, the strength of materials, we evade the difficulty, as we are content to assimilate the compact rod to the assemblage of its elementary fibres, close but unconnected, and thus exercising no mutual lateral actions. This voluntary error is excused, not only for the sake of simplification, but also because it appears to be of a kind which may be neglected in the presence of certain accidental irregularities which we provide for, as best we can, by modifying in the particular case the value of the coefficients. Thus, for example, iron wire, owing to its peculiar mode of manufacture by drawing, is relatively stronger than iron in thick bars.

It is admitted, then, that the tensile stress N which a rod can sustain is proportional to its section ω, that is, $N = R\,\omega$, where R designates the resistance to rupture per superficial unit of the section.

The phenomenon of change of form is successive and continuous, which distinguishes it from the instantaneous phenomenon called rupture. It may be followed by the eye, by observing the elongations δ of a unit of length of the rod under increasing loads N. The curve of which δ is the ordinate, and N $\left(\text{or } \frac{N}{\omega}\right)$ the abscissa, is not a straight line; its differential coefficient increases at first very slowly, and then more rapidly as it approaches rupture. Under moderate loads, however, we admit the proportionality of δ to N, and we always assimilate the rod whose section is ω to a bundle of independent fibres placed in juxtaposition. Hence the formula $N = E\,\omega\,\delta$, where E is the modulus of elasticity. If E varies in the section, we write $N = \delta \int E\, d\,\omega$. The factor $\int E\,\delta\,\omega$ is called the longitudinal spring. The resultant N of the tensions is understood to pass through the centre of elasticity.

Great importance has been attached, as a matter of principle, to the vague idea of the limit of elasticity. Below this limit the elongation δ would be proportional to the force N, according to the preceding formula, and it would vanish by the removal of the force, the rod then resuming its primitive length. It appears to be shown that it is necessary to distinguish two kinds of elongation, one permanent, a kind of wire-drawing, very inconsiderable at the commencement, but increasing rapidly and degenerating into enervation under considerable loads; the other elastic, that is, obeying the law of proportionality to the force and vanishing therewith. The permanent elongation would seem to present the character of not being renewed by the return of the same force or of smaller forces, in which case the law of elastic pulsation obtains freely. The limit of elasticity would be practically the point below which the permanent elongation is not appreciable.

These hypotheses, however, are open to doubt. Certain facts seem to establish that time intervenes as an enervating cause, by giving permanence to elongations which are at first elastic, and by consequently diminishing the vigour of the material to react against derangements. It has been remarked, that fibrous iron tends to acquire a granulated or crystalline texture by long-continued concussions. It might thus be apprehended that an iron beam which now is amply strong, might, even though protected from all oxidation, break fatally some day by the sole effect of the repeated action or long continuance of the load. If this is so, the theory of resistance ought, perhaps, to be changed in character; instead of saying vaguely that a certain material, subjected to certain work, presents guarantees of safety, it ought to announce for how long a period, or how many times, it will support the test with impunity. This doctrine of instability appears but too well supported by analogy; everything is stamped with the seal of destruction.

For the case of great stresses passing beyond the conventional limit of elasticity, Barré de St. Venant has proposed to substitute for the law $\frac{N}{\omega} = E\,\delta$, the expression $\frac{N}{\omega} = E\,[1 - (1 - \delta)^m]$, m being a number > 1.

Compression.—The resistance offered by two particles when caused to approach each other is indefinite, and a solid or even a liquid may support any pressure, distributed uniformly over its circumference in such manner that no particle can escape by sliding away. For example, it would be impossible to succeed in crushing the water contained in a hydraulic press.

What then is crushing? This word is applied to solids pressed irregularly upon different faces or portions of their external contour. The form ordinarily presented is that of prisms pressed only on their bases. Such a solid shortens, but its density does not augment in an equal proportion, because certain particles near the lateral contour flow to the exterior. The body swells, principally in the middle of its length; sometimes it exfoliates in filaments which detach themselves and fall away on various sides. These effects constitute crushing. They are due to internal sliding actions, calling into play the resistance of certain particles to lateral disjunction.

In prisms of very elongated form, the phenomenon is modified by the tendency of the middle of the rod to deviate altogether, from its original straight form, under the most imperceptible cause; thus flexure arises, and the moment of resistance of the rod becomes of more importance than the area of its section. Thus the case of a pillar pressed upon its bases is very imperfectly understood. We are almost reduced to the application of formulæ purely empirical, which aim rather at conforming to observed facts than at explaining them. They are valuable as expressing the results of numerous observations, as guides for ordinary practice, and as steps towards the discovery of laws. But the ideas latent in them are often masked by the divergent circumstances of the experiments, and the functions assume different forms under the hands of different observers. Generally, in practical construction, we apply to compressed prisms the same formulæ, $N = R'\omega = E\omega\delta$, as for rods in tension, when the length does not exceed, for example, ten times the thickness. For longer lengths recourse is had to experimental formulæ, or to the reduction, more or less arbitrarily, of the coefficient R′ of the pressure admissible per unit of surface. Love has reduced into formulæ the experiments of Hodgkinson on long columns.

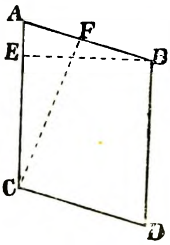
Researches have been made on the lateral bulging out of a compressed prism, or the analogous contraction of a stretched rod. For an isotropic body, that is, one which has a similar texture in every direction, St. Venant shows that a bulging $\frac{\delta}{4}$ of the transverse lineal dimensions corresponds to a proportional shortening $\delta = \frac{R}{E}$, of the length of the prism. In this way the unit of primitive volume will have become $= (1-\delta)\left(1+\frac{\delta}{4}\right)^2 =$ sensibly $1-\frac{\delta}{2}$.

Wertheim arrived at $\frac{\delta}{3}$ for the contraction of the volume instead of $\frac{\delta}{2}$. It must, however, be stated that the isotropic condition is merely a theoretical abstraction.

If it is true that compression is only dangerous on account of the lateral bulging which it causes, we may conclude from what precedes, that a prism may carry four times more by compression than by extension, provided that, by its short length or otherwise, it be preserved from all lateral bending. This conclusion, however, requires considerable modification in practice.

Sliding.—Two portions of a solid contiguous to a common section, tend to slide one upon another, when they are acted upon by a relative shearing force parallel to the section. The corresponding change of form is no longer a simple translation, but is an angular deformation. Having given a small parallelopiped, of which the base, at first rectangular, is deformed into an oblique parallelogram A B D C, Fig. 1740; then letting fall B E perpendicular to A C, we may say that the face projected on B D has moved before A C by the relative quantity $\frac{AE}{AB}$, and this motion is the same as that $\frac{AF}{AC}$ of C D before A B. In other words, the sliding between two parallel and neighbouring faces inclines their primitive common normal, and is measured by the projection on one of them, of the unit of length applied on the normal which has deviated. It is the small cosine acquired by the deformed angle which was originally a right angle.

1740.



This principal sliding g is in the same direction as the projection of the deviated normal. We estimate first the component slidings g' and g'' parallel to the directions of two rectangular axes traced beforehand on the section; then the principal sliding will be $g = \sqrt{g'^2 + g''^2}$.

The sliding action causes stretching of the fibres, for in every rectangle transformed into an oblique parallelogram one diagonal will be lengthened, the other diagonal will be contracted. The greatest stretching, and also the greatest contraction, per unit of length, will have the value of the half sliding $\frac{g}{2}$, and will be manifested in directions drawn at 45° to the face in question.

Up to a certain limit the sliding g is proportional to the shearing force F applied to the face whose area is ω. The change of form is thus defined by the formula $F = Gg\omega$, the coefficient G bears the name of the modulus of transverse elasticity; it will be constant like E within the limit of elasticity. If this modulus varies in different parts of the area ω, we write $F = g\int G\,d\omega$; and $\int G\,d\omega$ is what is called the transverse spring. If T represents the tangential resistance to sliding a unit of surface, we have $F = T\omega$. These formulæ only apply to a section of finite area ω, while this section is compelled to continue plane; for in the case where it is free to bend, there will arise an unequal distribution of the sliding in the various parts.

An isotropic substance, capable of supporting a longitudinal tension R per unit of surface, which extends it a quantity $\frac{R}{E}$, may resist a sliding of double this extent $= 2\frac{R}{E}$, or a tangential stress $T = 2\frac{GR}{E}$. St. Venant having been led to the ratio $\frac{G}{E} = \frac{2}{5}$ between the moduli of transverse and longitudinal elasticity, we have $\frac{T}{R} = \frac{4}{5}$ for the ratio of the tangential and longitudinal stresses producing equal fatigue.

Texture of Bodies.—In the absence of knowledge as to the irregularities which may exist in various parts of the same body, it is customary to consider the materials employed in construction as homogeneous. In some cases, however, we are aware of the irregularity; for example, we know that in cast iron, the external skin is of a closer texture than the internal mass, and we may take account of this by causing the coefficients E, G, R, T, to vary in different points of the section of the solid considered.

As to the texture at any given point, there are two ordinary cases;—

1. Amorphous or granular bodies, in which we assume a similar texture in all directions.
2. Fibrous substances, in which the texture is uniform in all the transverse directions perpendicular to the fibres, but is quite different in the directions of the fibres themselves. The coefficients which characterize this texture vary therefore in different directions like the radii of an ellipsoid of revolution. Experimental data, to be complete, ought to furnish the various relative coefficients for the principal directions, which ought to be applied, sometimes one and sometimes the other, according to circumstances.

We know, for example, with fir wood, how much easier it is to cause the fibres to slide upon each other, than to shear them transversely, and how much easier to separate them laterally than to break them by longitudinal tension.

If, in some cases, we admit an unequal texture in three rectangular directions, the tensions corresponding to different positions will be represented by the radii of an ellipsoid with three unequal axes.

Crystalline bodies present faces of cleavage which have little adherence, however hard may be the crystals themselves. This molecular constitution is too complicated to enter into the formulæ of strength, and therefore we should treat such substances as amorphous, attributing to them coefficients with a mean practical value.

Limits of Safety.—Experience furnishes the values of the coefficients R and T, which produce rupture by tension or fracture by shearing. In permanent constructions it is necessary to keep much within these limiting values. We therefore choose, somewhat arbitrarily, the limits of strength about $\frac{1}{10}$ for substances which are but slightly homogeneous, such as wood or stone, and from $\frac{1}{4}$ to $\frac{1}{6}$ for metals. The great difference between the coefficient admitted in practice, and that which produces rupture, is demanded not only by what has been said concerning the limit of elasticity, but also by the possibility of concussions or unknown vibrations, by the thousand small hidden defects of the substances, and finally in order to cover the defects of the theory itself.

The immense variety of nature renders the task of experimenters very indefinite. Every isolated trial has only an absolute value for specimens identical with that tried. The discussion is delicate, and it is only possible to give approximate mean values as general results. The origin, the dimensions, the mode of manufacture, the annealing, the age, the humidity, and many other circumstances influence the strength. The labours of Hodgkinson, Fairbairn, Rondelet, Morin, and other scientific men, have accumulated a great number of useful data regarding the principal materials of construction, and yet there remains much to be done in this vast field of practical investigation.

The imperfections of theory require also reserve in the choice of the limits of safety. Certain errors act in a favourable direction; but in ignorance of this it is often necessary to provide against them, by attributing to them an unfavourable effect. The improvement of the science ought to tend to realize an exact determination of the conditions of strength in all the parts of a work; for example, the most economical framework for a given structure will be that which would fail simultaneously in all its bars, when the strain is augmented to rupture. The scale of security, or the suitable interval between the practical coefficient and that of rupture, will always have a character more or less arbitrary, because it will be always more prudent, but more costly, to have a smaller than a greater stress upon the material.

False hypotheses arise either from ignorance of the laws of the material, or from the conditions differing too much from practice, or from the obligation to simplify the calculation, which otherwise might be inextricable. It is thus that in most cases we only consider the states of statical equilibrium, omitting the consideration of vibrations or dynamical effects. In a continuous beam of many spans we must begin upon the hypothesis of the invariability of the supports, although we cannot be unaware that a very slight error of level may overthrow all our calculations. We may also instance the shearing of a rivet: the formula assumes an equal distribution of the shearing force on all the elements to be sheared, in such a manner that the disjunction may take place everywhere at the same instant; and yet in reality the edge attacked will be crushed before the opposite edge has moved.

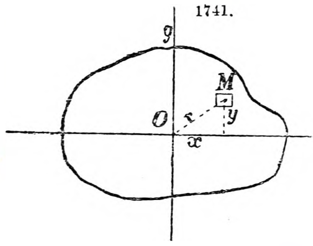
Torsion.—When a cylinder is twisted by a couple whose moment is $= \mu$, and whose plane is perpendicular to the axis of the cylinder, every transverse section turns, relatively to its adjoining section, round the axis passing through their centres of elasticity. If ϕ is the arc of torsion (relatively to the radius) per unit of length of the cylinder, and if ω is the sectional area, then an element $d\,\omega$ of this area, situated at a distance r from the axis, will suffer a stress $G\,\phi\,r\,d\,\omega$ in the direction of the tangent to the circle of radius r, G being the modulus of transverse elasticity or elasticity by sliding. The aggregate of these stresses, on the section ω, will be equal to a couple whose moment is $= \mu = \phi \int G\,r^2\,d\,\omega$. In the case of a homogeneous material, the moment of torsibility $\int G\,r^2\,d\,\omega$, may be written $G \int r^2\,d\,\omega$ or G J, where J is the polar moment of inertia $\int r^2\,d\,\omega$ of the section referred to its centre of gravity. The shearing stress T, a superficial unit, at a point distant r from the axis will be $T = \frac{\mu\,r}{J}$. The fibre passing through this point will be bent into a spiral, whose tangent of inclination, relatively to the axis, is $r\,\phi = \frac{\mu\,r}{G\,J} = \frac{T}{G}$. The maximum T_1 of the stress T will be at the circumference. Thus the section being a circle of a radius r_1, we have $T_1 = G\,g_1 = \frac{\mu\,r_1}{J} = \frac{2\,\mu}{\pi\,r_1{}^3}$; g_1 being the maximum sliding.

The relative sliding of two transverse sections involves an equal sliding of the fibres one upon another, and also an extension or compression of the spiral lines inclined at 45° to the axis of torsion.

The moment of torsion expressed by $G \phi J$ is exact for slight deformations of circular cylinders, or for very short prisms whose sections would be compelled to continue plane. But it would not apply to prisms whose transverse sections are free and not circular, for these sections give way and bend instead of remaining flat. In such a case the moment of torsion is less than $G \phi J$, and in order to determine it recourse must be had to the theory of St. Venant, now about to be explained.

Any element of the lateral free surface is carried along by the interior parallel and contiguous layer, without any relative sliding; for it would require an external tangential force, such as friction, to oblige the element to slide. Consequently the transverse sections of the prisms bend, in such a way as always to cut normally the lateral twisted surface. It is thus necessary to take account of this deformation, in estimating the real slidings tending to shear the fibres.

1741.



Trace two rectangular axes $O\,x$, $O\,y$, Fig. 1741, in the primitive plane section, and passing through the centre of elasticity O, or axis of torsion. An element M, whose distance from O is $r = \sqrt{x^2 + y^2}$, will have left the plane of the axes after the torsion, and we will call z its distance outside this plane. If we neglect this distance z, the inclination taken by the twisted fibre passing through M, in virtue of the arc of torsion ϕ, will produce simply a sliding $r\,\phi$ perpendicular to the radius r; this sliding may be decomposed into its projections;—$y\,\phi$ in the direction of the abscissa x, and $x\,\phi$ in that of the ordinate y. If, now, we suppose that the fibre has remained vertical, in order only to occupy ourselves with the displacement z, the small inclination $\frac{d\,z}{d\,x}$ will measure the sliding parallel to $O\,x$, and $\frac{d\,z}{d\,y}$ that parallel to $O\,y$. The composition gives $g' = \frac{d\,z}{d\,x} - y\,\phi$ for the effective sliding in the direction of x, and $g'' = \frac{d\,z}{d\,y} + x\,\phi$ for that in the direction of y. The principal sliding will be the resultant $g = \sqrt{g'^2 + g''^2}$.

Differentiating g' in respect to y alone, and g'' in respect to x, and reducing, we obtain the relation $\frac{d\,g''}{d\,x} - \frac{d\,g'}{d\,y} = 2\,\phi$.

The slidings g' and g'' are not only the slidings between transverse sections, which tend to shear the fibres. There are also the slidings of the fibre, relatively to its neighbours, following the small longitudinal faces, parallel respectively to x and y. If then the extreme bases of the fibre do not support the normal pressures, if the weight be neglected, and if the texture is similar in all the transverse directions, the longitudinal equilibrium of the fibre will require this general indefinite condition $\frac{d\,g'}{d\,x} + \frac{d\,g''}{d\,y} = 0$. According to the above given values of g' and g'' this condition is expressed by the equation of the partial differential coefficients of the second order

$$\frac{d^2\,z}{d\,x^2} + \frac{d^2\,z}{d\,y^2} = 0. \tag{1}$$

Further, there exists a special condition for the points of contour of the section, that is the condition of normality between the section and the lateral faces of the prism. It is necessary that the principal sliding shall become, at these points, tangential to the contour, which is expressed by $\frac{g''}{g'}$,

or

$$\frac{\frac{d\,z}{d\,y} + x\,\phi}{\frac{d\,z}{d\,x} - y\,\phi} = \frac{d\,y}{d\,x}. \tag{2}$$

Under the slidings g' and g'' the elements $d\,\omega$ of the transverse sections experience tangential or shearing actions, equal to $G\left(\frac{d\,z}{d\,x} - y\,\phi\right) d\,\omega$ in the direction x and equal to $G\left(\frac{d\,z}{d\,y} + x\,\phi\right) d\,\omega$ in the direction of y. These actions constitute, in the aggregate, a couple which resists the given moment μ of the external forces tending to twist the prism. We have thus

$$\mu = G \int_0^{\omega} \left[\left(\frac{d\,z}{d\,y} + x\,\phi\right) x - \left(\frac{d\,z}{d\,x} - y\,\phi\right) y\right] d\,\omega.$$

This expression determines the torsion ϕ; we find $\frac{d\,z}{d\,x}$ and $\frac{d\,z}{d\,y}$ by integrating equation [1] with the condition expressed by equation [2], adapted particularly to the given contour of the base of the prism.

As the direct application of the above presents great difficulties, St. Venant has contrived an expedient, which consists in assuming from the commencement the deformation z; then the contour of the base of the prism becomes the unknown quantity, and it is endeavoured, by the choice of z, to arrive at forms of contours which may be met with in practice. We need only give some of the most remarkable results.

For the cylinder with circular base, $x^2 + y^2 = a^2$ (a = radius), we find $z = 0$, that is, the sections continue plane. The moment of torsion has the value $\mu = G\,\phi \int (x^2 + y^2)\,d\,x = G\,\phi\,J$; $= \frac{\pi}{2} G\,\phi\,a^4$. The greatest shearing stress is produced at the circumference, and has the value $T = G\,a\,\phi = \frac{2\,\mu}{\pi\,a^3}$, the unit of surface. The circular section is the best of all solid forms for the resistance to torsion.

In the elliptic cylinder, $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$ (the ellipse having axes $= 2\,a$ and $2\,b$) the sections bend into hyperbolic paraboloids given by $z = \frac{b^2 - a^2}{a^2 + b^2}\,\phi\,x\,y$. The axes of the ellipse preserve their rectilinear direction; but hollows are produced in two opposite quadrants, and projections in the others. The moment of torsion is $\mu = \frac{a^3\,b^3\,\pi\,G\,\phi}{a^2 + b^2}$. The principal sliding $g = \frac{2\,\phi\sqrt{a^4\,y^2 + b^4\,x^2}}{a^2 + b^2}$ increases from the centre to the circumference; its greatest value takes place, not on the fibres farthest removed from the centre or axis of torsion, but at the extremities of the minor axis of the ellipse, points when $x = o$, $y = \pm b$. The greatest shearing stress is consequently

$$T = \frac{2\,G\,a^2\,b\,\phi}{a^2 + b^2} = \frac{2\,\mu}{\pi\,a\,b^2}.$$

In the equilateral triangular prism, whose side $= a$, the maximum sliding is produced at the middle of the sides, and the equation of resistance to shearing is $T = \frac{\sqrt{3}}{4}\,G\,a\,\phi = 20\,\frac{\mu}{a^3}$. The moment of torsion $\mu = \frac{\sqrt{3}}{80}\,G\,a^4\,\phi$ is only $\frac{3}{5}$ of the value $G\,\phi\,J$ which it would have on the hypothesis of sections continuing plane.

In the rectangular prism, whose sides are a and b, the solution is very complicated. The moment of torsion is expressed thus;—

$$\mu = G\,\phi\left[\frac{a\,b^3}{3} - \frac{64}{b}\,\Sigma\,\frac{e^{\frac{1}{2}m\,a} - e^{-\frac{1}{2}m\,a}}{m^5\left(e^{\frac{1}{2}m\,a} + e^{-\frac{1}{2}m\,a}\right)}\right];$$

or

$$\mu = G\,\phi\,b^3\left[\frac{a}{3} - 0{,}2101\;b + 0{,}4183\;b\left(\frac{1}{1^5}\cdot\frac{e^{-\frac{\pi\,a}{2\,b}}}{e^{\frac{\pi\,a}{2\,b}} + e^{-\frac{\pi\,a}{2\,b}}} + \frac{1}{3^5}\cdot\frac{e^{-\frac{3\,\pi\,a}{2\,b}}}{e^{\frac{3\,\pi\,a}{2\,b}} + e^{-\frac{3\,\pi\,a}{2\,b}}} + \cdots\right)\right],$$

a converging formula which may be restricted to the two first terms, when a exceeds $4\,b$. The letter e designates the base of the Napierian logarithms; Σ designates a sum embracing an infinite number of terms, obtained by substituting $\frac{(2\,n - 1)\;\pi}{b}$ for m and making successively $n = 1, 2, 3, \ldots \infty$. The dangerous points are at the middle of the greater sides a. The sliding is nothing at the sharp edges, although they would be the fibres most exposed if the sections had continued plane. Taking the moment $\mu = G\,\phi\,a\,b^3\left(\frac{1}{3} - K\frac{b}{a}\right)$, and the maximum shearing stress $T = K'\,G\,b\,\phi$, we should have for K and K′, according to different values of the ratio $\frac{a}{b}$ of the sides, the following values;

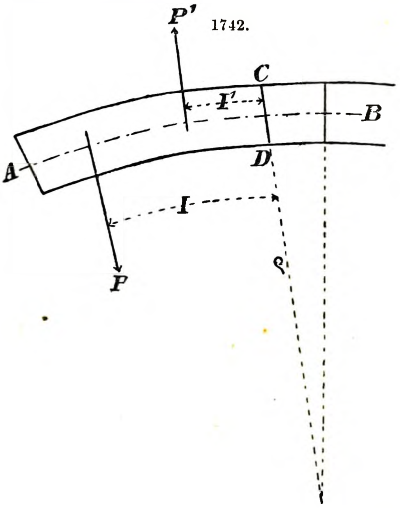
$\frac{a}{b} =$	1	1·1	1·2	1·3	1·4	1·5	1·8	2	3	∞
K =	0·193	0·197	0·201	0·203	0·205	0·206	0·208	0·209	0·210	2·210
K′ =	0·675	0·720	0·759	0·793	0·822	0·848	0·904	0·930	0·985	1·000

Sections in the form of a cross are unfavourable for torsion.

In the preceding formulæ, the coefficient G, of the elasticity of sliding, is supposed constant in all the transverse directions, but it may have another value in the longitudinal direction, as would be the case in prisms of wood. The formulæ may be modified to adapt them to the case where there are two different coefficients G′ and G″, in the directions of the abscissa x and the ordinate y, of the transverse section; but in practice the former case is the most important one.

Flexure.—Let A B, Fig. 1742, be a prism subjected to transverse forces P, P′, . . . which alter the primitive parallelism of the sections by bending all the fibres. Any section C D tends to turn as on a pivot under the action of the bending moment $\mu = \text{P}l - \text{P}'l' + \ldots$ exerted by the forces situated between this section and one of the extremities, A, of the solid. When the forces are all normal to the length of the prism, the mean fibre A B, locus of the centres of gravity of the sections for a homogeneous solid, bends into a curve without change of length. It separates the other fibres into two groups, one of which suffers elongations, the other contractions. These variations $\left(= \frac{v}{\rho}\right)$ are proportional to the distance v of the various fibres from the neutral section, and inversely proportional to the radius of curvature ρ due to the flexure.

1742.

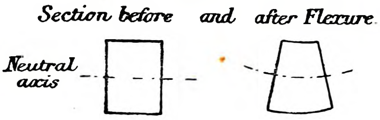


Now we know that an extended fibre contracts transversely, while a shortened fibre swells. It results from this that the section C D will change its form ; if, for example, it was rectangular, it will become a sort of curvilinear trapezium, Fig. 1743; the orthogonal lines traced in the primitive section will also be orthogonal in the deformed section.

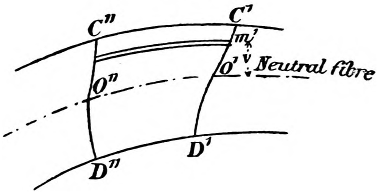
When the bending moment remains constant for a certain length of the solid, this length bends in the arc of a circle. This case of circular or equal flexure is the only one in which the transverse sections remain strictly a plane after deformation ; these sections remain normal to the arched fibres, and neither slidings nor lateral pressures are developed between the fibres.

When the prismatic solid is subjected to a bending moment which varies from one section to another, the flexure is said to be unequal. There are then produced slidings between the sections, and even between the fibres. The longitudinal slidings between the fibres develop, among themselves, tangential reactions or frictions of adherence, energetic in the neighbourhood of the central fibre, but which decrease and vanish in the fibres of the external contour which are supposed free. This law of the slidings compels the transverse sections, which were originally plane, to undulate in curved surfaces C′ O′ D′, Fig. 1744, cutting normally the external faces of the solid. Further,

1743.



1744.



the slidings between the different threads of particles, produce inverse effects of such a nature that no alteration occurs in the longitudinal stresses of the fibres; thus the fibre $m'm''$, having a section $= d\,\omega$, will be lengthened by a quantity $= \frac{v}{\rho}$ which implies a tension $\text{E}\,d\,\omega\,\frac{v}{\rho}$ the same as if the sections had remained plane in deviating, ρ designating the radius of curvature of the flexure of the element O O′ of the mean fibre, at first rectilinear. It is this which enables us to study the flexure on the simplifying hypothesis of the sections remaining plane, when we have only in view the tensions or compressions of the fibres. But when we wish to study the slidings, which, however, are less important, exactitude requires that we should consider the true form of the deviated sections, on which depends the variable sliding between the various fibres. The law of the curvatures C′ O′ D′ is such that the resultant of the lateral sliding resistances upon a fibre $m'\,m''$ is in equilibrium with the resultant $\text{E}\,v\,d\,\omega\left(\frac{1}{\rho'} - \frac{1}{\rho''}\right)$ of the pressures on the two bases, a resultant due to the variation of the radius of curvature ρ between O′ and O″. As to the effects of swelling and contraction shown in Fig. 1743, there is nothing to prevent their development without causing normal lateral pressures between the contiguous fibres.

The tension $\text{E}\,d\,\omega\,\frac{v}{\rho}$ of the element of fibre $m'\,m''$, Fig. 1744, has for its moment $\text{E}\,d\,\omega\,\frac{v^2}{\rho}$ relatively to the neutral axis of the transverse section. The integral of this last expression will express the moment of the elastic forces which ought to maintain in equilibrium the given bending moment μ exerted by the external forces applied to the solid. Hence the equation of elasticity $\frac{\text{E I}}{\rho} = \mu$, where I designates the moment of inertia, $= \int v^2\,d\,\omega$, of the section of the bent prism in respect to the neutral axis. This equation determines the curvature $\frac{1}{\rho}$ of the mean fibre. For a straight beam the curvature resulting from the simple flexure is generally very small, and is expressed approximately by $\frac{d^2y}{dx^2}$, in terms of the abscissa x and the ordinate y of any point of the mean fibre. It is necessary then to integrate twice the equation $EI\frac{d^2y}{dx_2} = \mu$ in order to arrive at the finite equation in terms of x and y of the deformed mean fibre.

The practical object in the calculation of the strength is, not so much to obtain this deformed figure as to establish the stability of the work. Now if the fibre most strained, C′, is at a distance v' from the neutral axis, we desire that its stress $E\frac{v'}{\rho}$ a superficial unit shall be limited to a given amount R. Substituting, then, $\frac{R}{v'}$ for $\frac{E}{\rho}$, we transform the equation of elasticity $\frac{EI}{\rho} = \mu$ into an equation of resistance $\frac{RI}{v^1} = \mu$, in which $\frac{RI}{v'}$ is the moment of resistance. According as the ordinate v' is taken on one side or the other of the neutral axis, R will designate the maximum tension or the maximum compression.

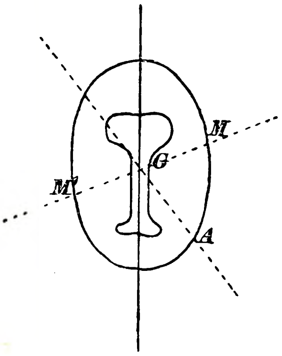
When the external forces, being always supposed situated in the plane of the figure, are not normal to the prism, they may exert, besides the moment of flexure μ, a longitudinal force N, spread uniformly over the area ω of the section. There are then two simultaneous effects compounded on the various fibres, and the equation of resistance becomes $R = \frac{N}{\omega} \pm \frac{v'\mu}{I}$. The mean fibre, the geometrical locus of the centres of gravity or of elasticity, is no longer neutral, for it has to resist the stress $\frac{N}{\omega}$. The neutral point, or point of no pressure, and the centre of stress, the point of application of the resultant of the stresses of the fibres, are situated on opposite sides of the centre of gravity, or of elasticity, of the section, following the same reciprocal law as the axes of suspension and oscillation in the compound pendulum.

Deviated Flexure.—We have, hitherto, only considered plane figures, assuming implicitly the symmetry of the solid and of the forces relatively to the plane of the figure. Let us now suppose, as before, that all the forces act in the same plane, but that this plane of "solicitation" is not in the direction of a principal axis of inertia of the transverse section considered.

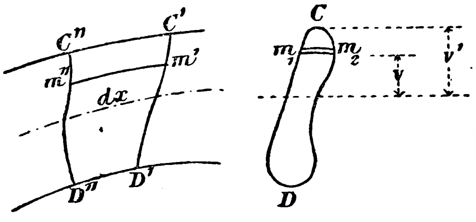
Let us revert, in the first place, to the idea of the ellipse of inertia. Take any section, as for example, a double T, Fig. 1745, calculate its moment of inertia round an axis G M, and then take a length GM or GM′, proportional to $\frac{1}{\sqrt{I}}$. If the axis GM be made to vary in direction by turning round G, the locus of the points M will be the ellipse of inertia relative to the point G; the ellipse is called central, when G is the centre of gravity of the section. As the ellipse possesses two principal axes, the given section, however irregular it may be, will also have two principal moments of inertia round the same rectangular axes. Now suppose that the plane of solicitation cuts the plane of the section otherwise than in the direction of a principal axis, as in the line G M, for example. Then the neutral axis round which the section pivots by the flexure will not be perpendicular to G M, but will follow the direction of the diameter G A, conjugate to G M in the ellipse of inertia. Consequently the mean fibre will, under the action of the force upon it, deviate outside the plane of solicitation.

This general case is but rare in practice. It is easily treated by the equation $\frac{RI}{v'} = \mu'$, taking care to refer I and v' to the neutral axis G A, and to take for μ', not the given bending moment μ, acting in the direction G M, but its projection μ sin. A G M, on the plane perpendicular to G A.

1745.



1746.



We may also decompose the oblique flexure into a flexure of descent and a flexure of deviation, produced respectively by the projections of μ upon the two principal planes of inertia. Then, when we wish to seek the fibre which is most strained, we must accumulate the stresses arising from the two component flexures.

For bent curved bodies, such as the arches of bridges, the equation of resistance, properly so called, will be the same as for a bent prism. But the study of the elastic deformation is more complicated. This deformation has an influence on the reaction of the supports, and consequently upon the bending moment.

Sliding due to Flexure.—When the bending moment μ arises from external forces not reducible to a couple, the resultant of the projections of these forces on the plane of the section constitutes a shearing force, causing slidings and undulations of the sections. When we already know the moment μ for the section whose abscissa is x, the shearing force upon the same section may be deduced therefrom, being simply the differential coefficient $\frac{d\mu}{dx}$.

The sliding on the section for any point is the same thing as the longitudinal sliding between the fibres. But in the case of a piece of wood, it must be remembered that this last sliding is the most to be feared, the fibres being more disposed to slide on each other than to shear transversely.

In the case of small sections, the sliding is determined approximately as follows;—Let Fig. 1746 C′ D′ and C″ D″ be the bent profiles of two neighbouring sections, and C D the form of those sections. The equilibrium of the portion C′ $m' m''$ C″ requires that the difference of the opposing pressures on its bases C′ m', C″ m'', shall be counterbalanced by the resistance of sliding upon $m' m'' = dx$. If the breadth $m_1 m_2$ is $= u$, this last resistance is expressed by $G g u\, dx$, or by $T u\, dx$; $G =$ modulus of elasticity, $g =$ sliding, $T =$ shearing stress a unit of surface. On the other hand, the small slice $m_1 m_2$, whose surface is $= u\, dv$, supports a normal pressure $\frac{\mu v}{I}\, u\, dv$; consequently C $m_1 m_2$ will support $\frac{\mu}{I}\int_v^{v'} u\, v\, dv$. The difference between two pressures, analogous and opposite, in passing from C′ m' to C″ m'', will be the differential relative to μ, that is $\frac{d\mu}{I}\int_v^{v'} u\, v\, dv$, or $\frac{F\, dx}{I}\int_v^{v'} u\, v\, dv$, where F is the shearing force $= \frac{d\mu}{dx}$. The equilibrium then gives

$$G g u = T u = \frac{F}{I}\int_v^{v'} u\, v\, dv.$$

If the section C D is rectangular, u is constant, and the maximum sliding which takes place on the neutral axis ($v = 0$) is $\frac{3}{2}$ of the mean sliding $\frac{F}{G\omega}$, where $\omega =$ area of section.

In a double T of plate iron, the middle web, whose thickness is e, and height $= h$, has in general a section $e\, h$, small in comparison to the top and bottom members; then $G g$ or T differs but little from $\frac{F}{e\, h}$, which leads us to calculate the middle web $e\, h$ as if it supported alone the shearing stress spread uniformly over its surface.

In constructions where the breadth u is not small, the transverse sections bend with a double curvature; the sliding may then vary notably upon this breadth.

Continuous Beams.—One interesting application of the theory of flexure, is that to continuous beams for bridges of several spans. The reactions exerted on the piers are external forces, which enter into the bending moment and the shearing stress. The difficulty of calculation of these reactions arises from their being dependent on the change of form; it is evident that, according to the way in which the continuous beam undulates under the loads, it may more or less relieve, or even quit altogether, certain supports in order to press more upon others. The absolute lifting off the supports being only an exceptional case, it is admitted as a fundamental hypothesis that all the points of the mean fibre corresponding to the piers and abutments are compelled to remain fixed, and consequently, for a straight horizontal beam, at the same invariable level; then the case of lifting off a support would be revealed by a negative value of the reaction, a value which would indicate the necessity of applying a counterweight, or an anchoring down, or making a new calculation by suppressing the useless support.

One of the earliest applications of the modern theory of continuous beams to practical engineering purposes was made by W. Pole in 1850, and will be found recorded in the M. I. C. E., vol. ix.; these calculations, corroborated by experiments made on a particular bridge, demonstrated that the adverse opinion of an inspector was erroneous, and prohibition to open the bridge was withdrawn.

The theory was further developed by Pole for the purpose of application to the Britannia Bridge, and the calculations were given by him in Clark's work on this structure.

Admitting combinations of load, of such a nature that the various spans carry loads uniformly distributed, but variable from one span to another, the equation of Clapeyron, which connects the bending moment upon three consecutive supports, resolves the problem in a convenient manner. Bresse has extended and enlarged this subject in the third part of his 'Mécanique Appliquée,' and he has placed the results within the reach of all practical men by means of an atlas, ready prepared, of diagrams of the maximum bending moments at all points. These only require a very simple transformation in the particular application; they only assume certain relations between one of the two extreme spans, which are equal, and one of the intermediate spans, which are also equal among themselves, but as the absolute lengths, as well as the intensities of the permanent and variable load, remain arbitrary, it is necessary to amplify the diagram according to the particular data, and at the same time to combine the ordinates of the permanent load and of the moving load or surcharge, on the same side of the axis of the abscissæ, in order to facilitate the comparative application of the moments of resistance.

The long calculations for bridges of many spans are therefore simplified, or even rendered unnecessary in ordinary cases. But the two following observations dictate a certain reserve in the application.

The formula of Clapeyron assumes the moment of inertia of the beam constant throughout its whole length. A more general hypothesis would render the calculation inextricable. Now the object is precisely to arrive at a considerable variation of the dimensions of the transverse section, by making it proportional to the magnitude of the stresses. When this alteration is effected the calculations are no longer exact; it would therefore be desirable that the theory should enable us to overcome the difficulty of the general case. According to the analogy of certain simple cases the adoption of the beam of equal resistance would only tend to augment from $\frac{1}{8}$ to $\frac{1}{6}$ the moments upon the supports, and to reduce slightly those at the middle of the spans. On this account the thicknesses in the neighbourhood of the piers should be slightly increased.

The hypothesis of points of support maintained at an invariable level is the most legitimate one upon which the formulæ can be established; but it must not be overlooked that the practical realization of this condition is scarcely under control, and if it is not entirely fulfilled, the calculations are incorrect. In every practical case we must expect slight irregularities or subsequent changes which alter the original regularity. Besides, even if the piers were mathematically levelled, we could not be sure that the beam should be so perfectly constructed that this mathematical accuracy should express its natural state previous to the action of the loads. It would seem that in order to acquire an exact knowledge of the conditions, it would be necessary to ascertain experimentally, the reactions exercised by the various piers, in order to compare them with those given by calculation.

Lattice girders may present, according as their bars are more or less close, all possible gradations between a state of rigidity similar to that of a solid side, and the state of a simple assemblage of jointed bars. Under the uncertainty that the question presents, it is customary to calculate lattice girders on the principle of jointed systems. The stiffness of the connections, which is neglected, appears in general to supply an additional guarantee of stability, assuming that the flexures are very small; for otherwise, the curvatures generated might falsify some of the results and cause increased stress on some of the bars.

Rupture imminent by Flexure.—When the elongation δ of a fibre becomes excessive, the tension is no longer expressible by $E\,\delta$, it is an unknown function $f\,(\delta')$. If the most extended fibre, situated at a height v' above the neutral axis, is stretched to an amount δ a unit of length, any fibre whatever of the ordinate v will lengthen a quantity $= \frac{v}{v'}\,\delta'$. Calling u the variable breadth of the transverse section, and marking the compressed parts with the index 1, the symbols v_1 being negative v's, the equilibrium of translation of the section first requires

$$\int_0^{v'} u\,d\,v\,f\left(\frac{v}{v'}\,\delta'\right) = \int_0^{v'_1} u_1\,.\,d\,v_1\,f_1\left(\frac{v_1}{v'}\,\delta'\right).$$

Then, in order to maintain the equilibrium of rotation against the bending moment μ, we must have

$$\mu = \int_0^{v'} u\,v\,d\,v\,.\,f\left(\frac{v}{v'}\,\delta'\right) + \int_0^{v'_1} u_1\,v_1\,d\,v_1\,.\,f_1\left(\frac{v_1}{v'}\,\delta'\right).$$

M. Barré de St. Venant has proposed to make

$$f\left(\frac{v}{v'}\,\delta'\right) = R\left[1 - \left(1 - \frac{v}{V}\right)^m\right]$$

for the stretched side, and

$$f_1\left(\frac{v_1}{v'}\,\delta'\right) = R_1\left[1 - \left(1 - \frac{v_1}{V_1}\right)^{m_1}\right]$$

for the compressed side, R and R_1 being, Fig. 1747, the stresses of rupture for tension and compression, at the distances V V_1 from the neutral axis. These distances would be diminished to v_1 and v'_1, at least one of them, at the instant of actual rupture. The exponents m and m_1 would be numbers > 1.

If it is the extended fibre which threatens to fail first, and it becomes necessary to limit the tension to a value R′, we put

$$R' = R\left[1 - \left(1 - \frac{v'}{V}\right)^m\right]$$

$$= \frac{m\,R\,v^1}{V}\left(1 - \frac{m-1}{2}\cdot\frac{v'}{V} + \frac{m-1}{2}\cdot\frac{m-2}{3}\cdot\frac{{v^1}^2}{V^2} - \ldots.\right).$$

Further, since experience seems to show that a similar law of proportion regulates the small tensions and the small compressions, it is desirable to unite tangentially at the neutral axis, the curves representing the tensions and the compressions of the fibres. This condition requires that

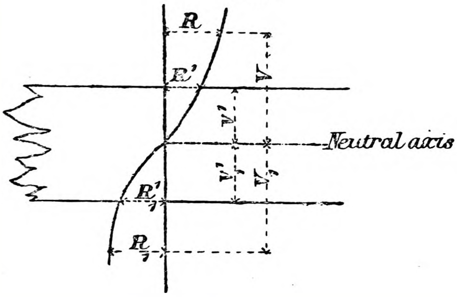
$$\frac{d\,f}{d\,v} = \frac{d\,f_1}{d\,v_1} \text{ for } v = v_1 = 0,$$

or

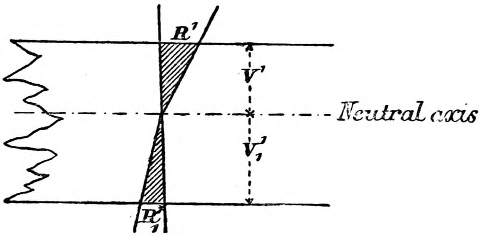
$$\frac{m\,R}{V} = \frac{m_1\,R_1}{V_1}.$$

Certain authors omit the condition just mentioned, and make the stresses vary uniformly, but a different rate for tension and for compression. Then the figure representing the pressures, Fig. 1748, will present a break upon the neutral axis; the two volumes shaded are equivalent by the condition of equilibrium of translation, which determines the situation of the neutral axis; and if the section is a rectangle whose breadth is $= a$ and height $= h$, the equation of resistance would be $\mu = \text{R}' \frac{a\,h\,v'}{3}$,

1747.



1748.



or $\mu = \text{R}_1' \frac{a\,h\,v_1'}{3}$. One or other of these formulæ is employed, according as it is the upper or lower fibre which ought first to fail. In every case the moment of resistance exceeds the value $\text{R}' \frac{a\,h^2}{6}$, which would be attributed to it by the ordinary theory.

The non-uniformity of the variation, or the adoption of the condition of tangential union at the neutral axis, as above mentioned, will also contribute to increase the moment of resistance. If, for example, it is the extended fibre which ought to give way, and if we admit the neutral axis at half the height by making

$$\text{V} = v',\ \text{R} = \text{R}',\ m = m_1,\ \text{R} = \text{R}_1,\ \text{V} = \text{V}_1,$$

we shall have

$$\mu = \text{R}' \frac{a\,h^2}{6} \cdot \frac{3\,m\,(m+3)}{2\,(m+1)\,(m+2)}.$$

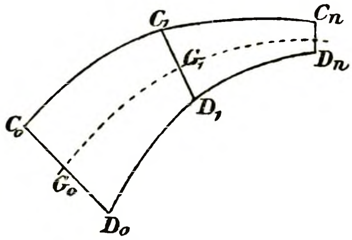
For cast iron we may be led to admit the law of uniform variation on the side of compression, that is, to make $m_1 = 1$, leaving m undetermined. Making, further, $\text{V} = v'$, $\text{R} = \text{R}'$, we should be led to

$$\mu = \text{R}' \frac{m\,a\,h^2 \left(3\,\frac{m+3}{m+2} + 4\sqrt{\frac{2}{m+1}}\right)}{6\,(\sqrt{2} + \sqrt{m+1})^2}.$$

Compound Deformations.—Any elastic solid may be subjected simultaneously to stresses of pressure, shearing, flexure, and torsion, which, in combination, may either increase or diminish their respective effects, according to the nature of the case.

Let $\text{C}_0\,\text{D}_0\,\text{D}n\,\text{C}n$, Fig. 1749, be a curved solid whose section varies slowly. In order to study the elastic forces developed on a section $\text{C}_1\,\text{D}_1$, we consider the action of the external forces applied between $\text{C}_1\,\text{D}_1$ and one, $\text{C}n\,\text{D}n$, of the extremities of the solid. These forces may produce, simultaneously, upon the section $\text{C}_1\,\text{D}_1$ a longitudinal stress $= \text{N}$, perpendicular to $\text{C}_1\,\text{D}_1$, a shearing stress $= \text{F}$, a bending moment $= \mu$, and a moment of torsion $= \mu'$. It will then be necessary to make a composition of the various motions excited by the different causes, in order to obtain the final displacement of the section $\text{C}_1\,\text{D}_1$. The shearing stress F, and the moment of torsion μ' would require, in exactness, that we should take account of the bending of the sections; but, attributing to them a slight influence in the problem, we shall content ourselves here with treating them as uniform shearing and cylindrical torsion. When we have expressed the elementary displacement of a section, it will be necessary to accumulate or integrate all these displacements between an initial section $\text{C}_0\,\text{D}_0$ and that $\text{C}_1\,\text{D}_1$ where we stop, in order to ascertain the definitive situation of this latter.

1749.



Let us now refer all to a system of rectangular axes $\text{O}x$, $\text{O}y$, $\text{O}z$. The index 0 will characterize the initial point G_0 of the mean fibre, and the index 1 the point G_1 under consideration. The sign Δ will indicate the increments; thus $\Delta\,x_1$ is the displacement, in abscissa, suffered by the point G_1 in virtue of its deformation. Let $\theta, \theta', \theta''$, and β be the respective angles which the axis of flexure or of rotation of the section makes with the co-ordinate axes $\text{O}x$, $\text{O}y$, $\text{O}z$, and with the plane of the moment μ. Let $\text{F}x$, $\text{F}y$, $\text{F}z$, be the projections of F on the axes; I the moment of inertia of the section referred to the axis of flexure; I′ its polar moment of inertia round the centre of gravity; ω its area; E and G the moduli of longitudinal and transverse elasticity; ds the elementary arc of the curve $G_0\,G_1$; and finally m_0, m'_0, and m''_0 the components of the rotation experienced by the initial section $C_0\,D_0$. The displacements of the point G_1 are expressed by the formulæ;

$$\Delta\,x_1 = \Delta\,x_0 + (z_1 - z_0)\,m'_0 - (y_1 - y_0)\,m''_0 + \int_{x_0}^{x_1}\left(\frac{\mathrm{N}}{\mathrm{E}\,\omega} + \frac{\mathrm{F}x}{\mathrm{G}\,\omega}\frac{d\,s}{d\,x}\right)d\,x$$

$$+ \int_{s_0}^{s_1}\left\{(z_1 - z)\left(\frac{\mu'}{\mathrm{G\,I'}}\frac{d\,y}{d\,s} + \frac{\mu \sin.\,\beta \cos.\,\theta'}{\mathrm{E\,I}}\right) - (y_1 - y)\left(\frac{\mu'}{\mathrm{G\,I'}}\frac{d\,z}{d\,s} + \frac{\mu \sin.\,\beta \cos.\,\theta''}{\mathrm{E\,I}}\right)\right\}d\,s;$$

$$\Delta\,y_1 = \Delta\,y_0 + (x_1 - x_0)\,m''_0 - (z_1 - z_0)\,m_0 + \int_{y_0}^{y_1}\left(\frac{\mathrm{N}}{\mathrm{E}\,\omega} + \frac{\mathrm{F}y}{\mathrm{G}\,\omega}\frac{d\,s}{d\,y}\right)d\,y$$

$$+ \int_{s_0}^{s_1}\left\{(x_1 - x)\left(\frac{\mu'}{\mathrm{G\,I'}}\frac{d\,z}{d\,s} + \frac{\mu \sin.\,\beta \cos.\,\theta''}{\mathrm{E\,I}}\right)\right.$$

$$\left. - (z_1 - z)\left(\frac{\mu'}{\mathrm{G\,I'}}\frac{d\,x}{d\,s} + \frac{\mu \sin.\,\beta \cos.\,\vartheta}{\mathrm{E\,I}}\right)\right\}d\,s;$$

$$\Delta\,z_1 = \Delta\,z_0 + (y_1 - y_0)\,m_0 - (x_1 - x_0)\,m'_0 + \int_{z_0}^{z_1}\left(\frac{\mathrm{N}}{\mathrm{E}\,\omega} + \frac{\mathrm{F}z}{\mathrm{G}\,\omega}\frac{d\,s}{d\,z}\right)d\,z$$

$$+ \int_{s_0}^{s_1}\left\{(y_1 - y)\left(\frac{\mu'}{\mathrm{G\,I'}}\frac{d\,x}{d\,s} + \frac{\mu \sin.\,\beta \cos.\,\theta}{\mathrm{E\,I}}\right)\right.$$

$$\left. - (x_1 - x)\left(\frac{\mu'}{\mathrm{G\,I'}}\frac{d\,y}{d\,s} + \frac{\mu \sin.\,\beta \cos.\,\theta'}{\mathrm{E\,I}}\right)\right\}d\,s.$$

If an elevation of temperature produced a linear dilatation τ, we should take account of it by adding respectively, to the first members of these three formulæ, the terms

$$\tau\,(x_1 - x_0),\ \tau\,(y_1 - y_0) \text{ and } \tau\,(z_1 - z_0);$$

but at the same time it would be necessary to introduce into the estimation of N, F, μ, and μ' the forces which would result from external obstacles opposed to the dilatation.

Besides the displacement of the point G, it is necessary also to ascertain the rotation suffered by the corresponding section $C_1\,D_1$. The components of this rotation, in the direction of the three co-ordinate axes, are

$$m_1 = m_0 + \int_{x_0}^{x_1}\left(\frac{\mu'}{\mathrm{G\,I'}} + \frac{\mu \sin.\,\beta \cos.\,\theta}{\mathrm{E\,I}}\frac{d\,s}{d\,x}\right)d\,x;$$

$$m'_1 = m'_0 + \int_{y_0}^{y_1}\left(\frac{\mu'}{\mathrm{G\,I'}} + \frac{\mu \sin.\,\beta \cos.\,\theta'}{\mathrm{E\,I}}\frac{d\,s}{d\,y}\right)d\,y;$$

$$m''_1 = m''_0 + \int_{z_0}^{z_1}\left(\frac{\mu'}{\mathrm{G\,I'}} + \frac{\mu \sin.\,\beta \cos.\,\theta''}{\mathrm{E\,I}}\frac{d\,s}{d\,z}\right)d\,z.$$

The most useful application is that to the arches of metal bridges. There is then no torsion μ', and even the shearing stress F may also be neglected as of slight influence. Moreover, the forces are weights all acting in the plane of symmetry of the arch, and the deformation is plane ($\Delta\,z_1 = 0$). The span, $= 2\,a$, of the arch is supposed to be maintained invariable by perfectly stable abutments. We therefore annul, in the expression of $\Delta\,x_1$, the quantities $\Delta\,x_1$, $\Delta\,x_0$, y_1, y_0, and x_0; we make $x_1 = 2\,a$, $\sin.\,\beta = \cos.\,\theta'' = 1$, and we are led to

$$2\,\tau\,a + \int_0^{2a}\left(\frac{\mu\,y}{\mathrm{E\,I}}\frac{d\,s}{d\,x} + \frac{\mathrm{N}}{\mathrm{E}\,\omega}\right)d\,x = 0.$$

When a point of the section of a solid is subjected, simultaneously, to a longitudinal extension δ_x a unit of length, to a lateral extension δ_y normal to the preceding, and to a transverse sliding g, these effects combine in a resultant stretching, which is variable in the different assignable directions. In one direction r, making, on the plane $x\,y$, an angle a with the longitudinal axis of x, the elongation, which is supposed small, is expressed by

$$\delta_r = \delta_x \cos.^2 a + \delta_y \sin.^2 a + g \sin.\,a \cos.\,a.$$

The maximum takes place in the direction determined by

$$\tan.\,(2\,a) = \frac{g}{\delta x - \delta y};$$

and its value is

$$\tfrac{1}{2}\,(\delta x + \delta y) + \sqrt{(\delta x - \delta y)^2 + g^2}).$$

If δy is only the lateral contraction $-\,k\,\delta x$, caused by the extension δx, the maximum resulting elongation will be

$$\frac{1-k}{2}\,\delta x + \tfrac{1}{2}\sqrt{(1+k)^2\,\delta^2 x + g^2}.$$

The value of k has little influence; admitting $k = \tfrac{1}{4}$, the formula will be

$$\tfrac{3}{8}\,\delta x + \tfrac{1}{2}\sqrt{\tfrac{25}{16}\,\delta^2 x + g^2}.$$

Thus, in order to confine the maximum stretching to a given limit $\frac{R}{E}$ or $\frac{T}{2\,G}$, it will be necessary to put

$$\frac{(1-k)\,E\,\delta x}{2\,R} + \sqrt{\frac{(1+k)^2\,E^2\,\delta^2 x}{4\,R^2} + \frac{G^2\,g^2}{T^2}} \leqq 1$$

for all the points of the solid; R is the given limit of tensile stress and T that of shearing stress. If the body is fibrous in the longitudinal direction, the formula holds good with a simple alteration of the value of k, provided that the texture is the same in all the transverse directions.

In the case where the body is only subjected to a longitudinal tension N, accompanied by a shearing stress F, the former of these forces, considered as isolated, requires a section $\omega''' = \frac{N}{R}$; the other demands a different area ω''; for example, $\omega'' = \frac{F}{T}$ if the section continues plane, or $\omega'' = \frac{3}{2}\,\frac{F}{T}$ for a thin rectangle bent edgewise. Then the equation of cohesion would lead us to deduce from this the effective area ω suitable to the two stresses superposed; that would be

$$\omega = \left(\frac{1-k}{2}\right)\omega''' + \sqrt{\frac{(1+k)^2\,\omega'''^2}{4} + \omega''^2}.$$

If N were a compression, we might make $\omega''' = k\,\frac{N}{R}$, k being about $\tfrac{1}{4}$, and we should have

$$\omega = -\,(1-k)\,\frac{\omega''}{2\,k} + \sqrt{\frac{(1+k)^2\,\omega''^2}{4\,k^2} + \omega''^2}.$$

Suppose, in addition to N and F, a bending moment μ acting in the direction of a principal axis of inertia of the section. The greatest extension is $\frac{N}{E\,\omega} + \frac{\mu\,v'}{E\,I}$, accompanied by a sliding $g = \frac{F}{G\,\omega}$, admitting the case where the section is preserved plane. If we calculated the section for F alone, we should make it $\omega'' = \frac{F}{T}$; supposing N to be tension, we should make $\omega''' = \frac{N}{R}$; or, if N is compression, $\omega''' = k'\,\frac{N}{R}$; finally the flexure μ, being isolated, would require a moment of inertia I_0, given by $\mu = R\,\frac{I_0}{v_0'}$. We write here v'_0, and not v', because the dangerous fibre may not be the same in the case of simple μ as in the compound case. Then the effective section ω, and its effective moment of inertia I, ought to satisfy, in the compound case, the equation

$$\left(1 - \frac{\omega'''}{\omega} - \frac{I_0\,v'}{I\,v_0'}\right)\left(1 + k\,\frac{\omega'''}{\omega} + k\,\frac{I_0\,v'}{I\,v_0'}\right) = \frac{\omega''^2}{\omega^2},$$

N being tension; or

$$\left(1 + \frac{\omega'''}{k'\,\omega} - \frac{I_0\,v'}{I\,v_0'}\right)\left(1 - \frac{k\,\omega'''}{k'\,\omega} + k\,\frac{I_0\,v'}{I\,v_0'}\right) = \frac{\omega''^2}{\omega^2},$$

N being compression.

In a beam which bends freely, with distortion of the sections, it suffices to attribute to the section the strongest of the dimensions required successively by the flexure alone and by the sliding alone.

The theory may be extended to the case where the contexture of the body varies symmetrically round three rectangular planes, but we will pass over this case.

Different stresses, combined, may weaken themselves mutually, instead of magnifying themselves; thus a transverse compression may allow an augmentation of longitudinal stretching, as if it filled the empty spaces between the molecules which are determined by this stretching.

An application which occurs in ordinary practice, is that in machinery of a round or square shaft, which is at the same time subject to forces both of torsion and bending.

Let it first be a circular cylinder, of a texture uniform transversely. This cylinder, whose radius

$= r$, is twisted by a moment μ', bent by a moment μ, and further is stretched by a longitudinal stress N. The torsion μ' produces a sliding $= \frac{2\,\mu'}{G\,\pi\,r^3}$, and the theory leads to the following equation for the fibre the most strained.

$$\left(\pi\,r^3 - \frac{4\,\mu}{R} - \frac{N\,r}{R}\right)\left[\pi\,r^3 + \frac{k'}{R}(4\,\mu + N\,r)\right] = \frac{4\,\mu'^2}{T^2};$$

R designates the maximum working coefficient of tension, $\frac{R}{k'}$ that of compression, and T that of shearing. Calling r', r'', r''' the radii which would suffice respectively if the shaft was only bent, only twisted, or only stretched, that is to say,

$$r' = \sqrt[3]{\frac{4\,\mu}{\pi\,R}},\ r'' = \sqrt[3]{\frac{2\,\mu'}{\pi\,T}},\ \text{and}\ r''' = \sqrt{\frac{N}{\pi\,R}},$$

the equation of resistance, which determines the effective radius r, may be written,

$$(r^3 - r\,r'''^2 - r'^3)\,(r^3 + k'\,r\,r'''^2 + k'\,r'^3) = r''^6.$$

If N were a compression we should make $r''' = \sqrt{\frac{k'\,N}{\pi\,R}}$, and the equation would be,

$$\left(r^3 + \frac{r\,r'''^2}{k'} \mp r'^3\right)(r^3 - r\,r'''^2 \pm k'\,r'^3) = r''^6.$$

The upper signs belong to the upper fibre, and the lower ones to the lower fibre; for it is one or other of these fibres which is most threatened. The coefficient k' having little influence, we may take it $= \frac{1}{4}$.

For a revolving square shaft, twisted (μ') and bent (μ), the flexure will be generally produced with deviation which complicates the problem. St. Venant has given a table of the results for a series of positions of the shaft. If the flexure predominates, the diagonal position is the most dangerous, and the side c of the square is determined by the equation $\frac{R\,c^3}{\mu} = 6\sqrt{2}$. If, on the contrary, the torsion prevails, we must consider the instant when the sides of the section are horizontal and vertical; that is the dangerous case when $\frac{R\,\mu'}{T\,\mu}$ is greater than 1·037, and we then take,

$$\frac{R\,c^3}{\mu} = \frac{9}{4} + \sqrt{\frac{225}{16} + 23077\left(\frac{R\,\mu}{T\,\mu}\right)^2}.$$

Combination of different Materials.—A simple jointe system, analogous, for example, to the simple triangular framing of the Crumlin Viaduct, as originally constructed, may admit without inconvenience the combination of heterogeneous materials; for example, cast iron or wood in the compressed bars, and wrought iron for the ties. Each piece, in effect, is free to apply its power, with the modulus of elasticity properly belonging to it, without risk of involving other pieces beyond their limits of strength. But, in the ordinary cases, more complicated, it will often be difficult to make the heterogeneous members work well together in such a manner as to utilize them all in the best possible way, and within the limits suitable for them respectively. The formulæ of deformation must be referred to in order to ascertain whether the play of a piece is limited by its connection with another. If, for example, we split a wooden beam in order to strengthen it with a vertical web of plate iron enclosed and pressed between the parts, it will be necessary to establish a suitable ratio between the depths of the wood and of the iron, if we desire that each of the two materials may be strained in given degrees.

Dynamical or "Living" Resistance.—The resistance of solids exposed to shocks or vibrations is scarcely treated, in the present state of science, by any other than empirical rules, which amount to a reduction of the value admissible for the coefficients of safety. The mode of resistance, properly speaking, is always the same; the difficult point is solely the determination of the greatest stresses acting on the material.

Let us consider a cord holding a body in its fall. At the moment when the cord becomes stretched, the movable body is animated by a known *vis viva;* and at the end of an instant the cord elongates by a quantity z_1, exerting an increasing effort F, of which the work $\int_0^{z_1} F\,dz$ has extinguished the *vis viva;* then the motion is stopped, or rather, there are produced thenceforward a number of inverse oscillations, because the elongation z_1 is too great to maintain a simple statical condition. If the variable stretching z of the cord or rod remains but small, the tension F may be expressed by $\frac{E\,\omega\,z}{l}$, E being the modulus of elasticity, ω the section of the rod, and l its length. Then the resisting work is

$$= \frac{E\,\omega}{l}\int_0^{z_1} z\,dz = \frac{E\,\omega\,z_1^2}{2\,l}.$$

In order to verify the strength, it will suffice to equate this expression with the *vis viva* which expresses the shock undergone, added to the work $P\,z_1$ of the weight P of the body during the stretching, and then to show that the elongation $\frac{z_1}{l}$ a linear unit deduced from the equation does not exceed the limit admissible consistently with safety. If there be no initial shock, the body being set free without velocity at the moment when the cord begins to stretch, the elongation of the latter attains double the statical amount.

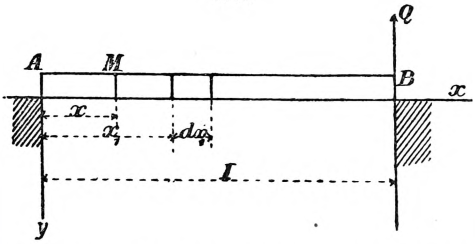
When a rail is tested by the shock of a falling weight, there occurs a phenomenon which is complicated under two points of view; in the first place, because the rules of mechanics only give a rough idea of the maximum intensity of the reaction developed by the shock; and secondly, because the test, in order to be conclusive, ought to be extended to near rupture, beyond the limit of elasticity. Hence it must be left to the province of direct experience to decide the legitimate intensity of the shocks that should be prescribed. Certain observations made on bars of cast iron have appeared to show that the shock of rupture depends solely on the area of the section, and little or nothing on its moment of inertia. This is a fact that requires explanation.

Certain mechanical organs which are constructed expressly to receive shocks, such as hammers, for example, cannot pretend to the conditions of resistance applied to objects less strained. The face of a hammer will necessarily undergo a continuous work of permanent deformation or gradual drawing out; that is a question of wear; the remedy consists, less in the dimensions, than in the durability of the metal employed.

Slight vibratory movements should be viewed differently from shocks properly so-called. They produce actions less intense or less concentrated, but they are present in all machines, in bridges, and other structures. They affect, therefore, the majority of permanent buildings, to which the theory of strength is applied. But unfortunately the laws of these periodical motions are so complicated, that it will be a long time, without doubt, before any of the results obtained by theoreticians become available in practice.

In principle the difference that exists between a question of dynamical resistance or elasticity and the same question viewed statically, rests in the introduction of the forces of inertia. Then, according to the theorem of D'Alembert, there will be a fictitious equilibrium between the given applied forces, the molecular stresses developed by the stretching of the fibres, at the instant considered, and finally the forces of inertia which depend on the actual acceleration of the motion. Hence we cannot escape the necessity of considering the law of this intermolecular movement. Scientific researches on vibrations have been made by various authors, especially by Phillips and Bresse. We will indicate the results of an interesting case, considered by Bresse, that of the transverse oscillations of a beam; this case will at least show the complex form of the expression.

1750.



Transverse Vibrations for a Homogeneous Beam, of constant section, placed on two supports A and B, Fig. 1750, and carrying, a running metre, a permanent load p, and a movable surcharge or load p'. The support B exercises a reaction = Q; the support A is taken for the origin of the co-ordinate axes A x, A y; the length of the beam is $= l$. In the statical condition, the ordinate of flexure of the mean fibre at the point M, whose abscissa is $= x$, would be

$$y = (p + p') \frac{x\,(x^3 + l^3 - 2\,l\,x^2)}{24\ \mathrm{E\,I}},$$

E being the modulus of elasticity and I the moment of inertia of the section, assumed constant. In the case of motion, the inertia would intervene. An element $d\,x_1$, of the portion M B would have, in the time t, a force of vertical inertia

$$= -\frac{p + p'}{g}\,d\,x_1\,\frac{d^2\,y_1}{d\,t^2}$$

where g designates the acceleration due to gravity. Further, the proper mass $\frac{p\,d\,x_1}{g}$ of the element would have sustained a small rotation $-\frac{d\,y_1}{d\,x_1}$, whence the angular acceleration $-\frac{d^3\,y_1}{d\,x_1\,d\,t^2}$, and, consequently, the couple of inertia

$$-\frac{p\,r^2\,d\,x_1}{g}\;\frac{d^3\,y_1}{d\,x_1\,d\,t^2}\,.$$

The letter r designates the radius of gyration of the section. The bending moment is then

$$\mathrm{E\,I}\frac{d^2\,y}{d\,x^2} = \int_x^l \left(1 - \frac{1}{g}\frac{d^2\,y_1}{d\,t^2}\right)(x_1 - x)(p + p')\,d\,x_1 - \int_x^l \frac{p\,r^2}{g}\,\frac{d^3\,y_1}{d\,x_1\,d\,t^2}\,d\,x_1 - \mathrm{Q}\,(l - x).$$

Differentiating twice, we get rid of the signs of integration and of the reaction Q, and we have this equation of the partial differentials of the fourth order.

$$\mathrm{E\,I}\frac{d^4\,y}{d\,x^4} = (p + p')\left(1 - \frac{1}{g}\frac{d^2\,y}{d\,t^2}\right) + \frac{p\,r^2}{g}\;\frac{d^4\,y}{d\,x^2\,d\,t^2}\,.$$

We arrive at the integration of this equation by means of series. The arbitrary quantities introduced are determined by the conditions of the problem; and especially according to the initial state in which the beam is considered. It is clear, for example, that if this initial state is that capable of maintaining the equilibrium, no vibrations would be produced; for the forces of inertia only exist, by the hypothesis, through the fact of a primitive anomalous state, which compels the molecules to seek their equilibrium; in pursuing it they pass alternately on one side and on the other, from which circumstance the vibrations arise. Let us then suppose to be given the functions $\phi(x)$ and $\Psi(x)$, which represent respectively the ordinate of flexure y and its differential coefficient $\frac{dy}{dx}$ in the initial instant, $t = o$. By making

$$\phi(x) - (p + p')\frac{x(x^3 + l^3 - 2lx^2)}{24\,\mathrm{E\,I}} = f(x),$$

then $\frac{\mathrm{E\,I}g}{p+p'}, = h^4$, and $\frac{p\,r^2}{p+p'}, = b^2$, the integral which will express the variable flexure y at every time t, is

$$y = (p + p')\,x\,\frac{(x^3 + l^3 - 2\,l\,x^2)}{24\,\mathrm{E\,I}}$$

$$+ \frac{2}{l}\sum_{i=1}^{i=\infty}\left(\sin.\frac{i\pi x}{l}\,.\cos.\frac{i^2\pi^2h^2t}{l\sqrt{i^2\pi^2b^2+l^2}}\int_0^l \sin.\frac{i\pi x}{l}f(x)\,dx\right)$$

$$+ \frac{2}{\pi^2h^2}\sum_{i=1}^{i=\infty}\left(\frac{\sqrt{i^2\pi^2b^2+l^2}}{i^2}\sin.\frac{i\pi x}{l}\,.\sin.\frac{i^2\pi^2h^2t}{l\sqrt{i^2\pi^2b^2+l^2}}\int_0^l \sin.\frac{i\pi x}{l}\,\psi(x)\,dx\right).$$

The sums Σ comprise an infinite number of terms, the quantity i taking all integral positive values. The duration of the period

$$= \frac{2\,l}{\pi h^2}\sqrt{i^2\pi^2b^2 + l^2}$$

varying with i, the movement is not periodic, but is produced by the superposition of an infinite number of periodical movements. The strict periodicity would obtain in the case where p would be null; then the duration of the oscillation would be

$$= \frac{2\,l^2}{\pi}\sqrt{\frac{p'}{\mathrm{E\,I}g}}.$$

If the beam is taken without deformation and without velocity at the origin of the time, that is to say, $\phi(x) = \Psi(x) = o$, the equation of motion is reduced to

$$\frac{24\,\mathrm{E\,I}\,y}{p+p'} = x^4 + l^3x - 2\,l\,x^3$$

$$-\frac{96\,l^4}{\pi^5}\sum_1^\infty \frac{1}{i^5}\sin.\frac{i\pi x}{l}\,.\cos.\frac{i^2\pi^2h^2t}{l\sqrt{i^2\pi^2b^2+l^2}};$$

the sum Σ only extending to the unequal values of i. The motion is nearly periodic, by reason of the quick convergence of the series. The maximum deflexion, thus produced by the sudden application of a load without velocity, reaches double the amount of the statical deflection.

When it is wished to consider the influence of the velocity v of transport, by which the extra load may be moved along the beam, it must be remarked that this velocity is equivalent to a centrifugal pressure, nearly vertical, in consequence of the curvature of the trajectory which the movable body is led to follow on the bent beam. The calculation shows, that under the centrifugal action alone, the maximum bending moment might rise to

$$(p + p')\frac{\mathrm{E\,I}g}{p'v^2}\left(\frac{1}{\cos.\frac{v\,l}{2}\sqrt{\frac{p'}{\mathrm{I}g}}} - 1\right),$$

instead of the statical value $\frac{(p+p')\,l^2}{8}$, on the hypothesis that the moving load is renewed at one extremity in proportion as it leaves the beam at the other. Practically, it might be admitted, that the rolling velocity increases by about one-third the statical effects.

In conclusion, it may be remarked, that the theory of the strength and resistance of materials touches obscure problems of the physical constitution of bodies; and yet its practical character obliges it to be simple. Another motive, also, justifies the departure from rigorous exactness, that is, the irregularity of the material facts; if it is good, in effect, to associate mathematical science with physical phenomena, it is incontestable that these two elements, one always logical, the other often capricious, are often divorced from each other. It is on the latitude of the coefficients admitted in practice, that the foundation of security rests, destined to provide both against the risks of the material used and the errors of theoretical hypotheses.

Gaudard states that he has only endeavoured to lay down the most general theoretical ideas in seeking to bring to view the bases more or less controvertible of the formulæ adopted. It is in reality necessary to weigh well the value of these bases, in order either to appreciate the modifications to be observed in their application, or to discover improvements in them.

In spite of these imperfections, the theory of the strength and resistance of materials in its present state, constitutes an admirable and useful doctrine, which ought to be better known by the majority of constructing engineers, so much does it tend to impress boldness and elegance on designs of all kinds.

MERCURY.

The deposit of mercury worked at Almaden, in Spain, consists of three parallel and nearly vertical beds of grit or quartzite, impregnated with cinnabar. The length of the workable portions of these is 150 to 180 metres, and the thickness of each is from 3 to 8 metres. Their direction is approximately east to west. The most southern is termed the vein San Pedro y San Diego, and the two others, which lie close together, are known as San Francisco and San Nicolas. The vein San Pedro y San Diego consists of a white grit, regularly impregnated with cinnabar, which gives it a beautiful vermilion colour, particularly towards the western end, where it is richest. Towards the west, the deposit ends abruptly against a mass of schist. Towards the east, it becomes gradually poorer, and passes insensibly into ordinary white quartzite. The eastern end also becomes poorer in going down; so that the rich portion forms, in the deposit itself, a column dipping to the west. The grit forming the veins San Francisco and San Nicolas is black, and harder, more compact, and less regularly and less richly impregnated with cinnabar than that of the other. The beds of grit rich in cinnabar are contained between other barren beds, in some places of schist, and in others of quartzite.

The mine is worked by ten levels, of which the lowest is about 289 metres below the mouth of the San Teodoro shaft. The first four levels, down to 140 metres from the mouth of the shaft, are ruinous and inaccessible.

In the lower levels the deposits become more extensive, thicker, richer, and more regular. The veins San Francisco and San Nicolas approach each other in going down, and in parts join into one at the ninth level, the lowest at which they have been worked; and both approach nearer to the vein San Pedro y San Diego, so that it seems likely that at a still greater depth they will all join into one mass.

At the fifth level, which has now been long worked out, the ore was of very inferior quality. At the sixth it was chiefly poor ore, containing 1 to 7 or 8 per cent. of mercury, with a few masses of "medium ore," containing 8 to 20 per cent., at the ends of the veins San Francisco and San Nicolas. At the seventh level rich ore appeared, containing over 20 per cent., and in some instances as much as 80 or 85 per cent. of mercury; and the proportion of this increases in going lower, until the tenth level, so far as it has been opened, yields nothing else.

When medium or rich ore is calcined so as to expel the sulphur and mercury, the siliceous residue left is porous and friable, or even crumbles into sand. A portion of the substance of the rock seems thus to have absolutely disappeared, and to have been replaced by cinnabar. The period at which the cinnabar was thus introduced cannot be determined with any approach to certainty. Its introduction was evidently not contemporary with the deposition of the Silurian and Devonian beds in which it occurs, and dates probably, like that of the cinnabar found in the Palatinate, and at Vallata, near Agordo, from the close of the Permian epoch. It is thus distinctly older than the Idrian deposit of cinnabar, which is regarded as belonging to the Triassic period.

The workings of the Almaden mine communicate with the surface by three shafts, of which one is sunk to the depth of the tenth level, and the others to a little below the ninth.

The upper levels are at irregular distances apart; but in those recently driven, the depth from one to the next is fixed at 25 metres.

The method of working now in use was adopted about the year 1804. Its essential feature is the use of cross arches and walls of massive masonry, to support the sides of the excavations when the ore has been removed.

Where the veins San Francisco and San Nicolas come close together, the ground between them is entirely removed, and the main arches are turned from the south wall of the one to the north wall of the other.

The work underground is nearly all done by contract. Between 700 and 800 men are employed in the mine in the course of each day, in six-hour shifts, but the whole number engaged is much greater than this, from 2250 to 2500, as the men do not, on the average, work more than one shift of six hours every three days, and those occupied in the work that is most injurious to health, the miners breaking out the ore, and the masons engaged in underground walling, do not work more than one shift in five or six days.

Until 1873, the raising of the ore in the shafts was done wholly by horse-power, the only engine in use having been an old pumping engine, by Watt, erected in 1791. There is now a good winding engine at each of the three shafts, two being used for ore and materals, and the third for sending up and down the men.

The amount of pumping required is very limited, the quantity of water raised being only from 15,840 to 18,480 gals. in the twenty-four hours. It is lifted from the seventh level by the winding engine of the principal shaft, and so much as comes in below this level is pumped up to it by hand.

The ventilation is effected by natural circulation, aided, especially in summer, by a Guibal fan at the top of the upcast shaft.

The ore raised contains on the average 7·5 to 9 per cent. of mercury. It is sorted by hand into three classes;—

Metal	containing from	21·5 to 25	per cent.
China	„ „	6 „ 7·5	„
Solera	„ „	0·3 „ 0·8	„

Two forms of furnace are in use; the Bustamante furnaces, introduced in 1633, and so-called Idrian furnaces, adopted about the commencement of the present century.

There are twenty Bustamante furnaces, arranged in pairs. The furnace proper of each consists of a vertical cylinder of masonry, 2 metres in inside diameter and 6·60 metres high, which is fitted with charging openings in the side and at the top, and divided about the middle of its height by an arch of perforated brickwork. The upper part receives the charge of ore, and the lower is the fireplace. The fuel used is brushwood. A chimney communicating directly with the fireplace promotes the draught, and carries off the greater part of the smoke.

Openings lead from the upper part of the furnace to twelve parallel rows of earthenware condensers or aludels. Each of these is in the form of a vase, open at top and bottom, and they are inserted one in the next, to the number of forty-five or fifty in a row, and well luted at the joints, forming twelve small flues, of variable section and with thin walls. They open at the end into low chimneys, two to each furnace, fitted with dampers for the regulation of the draught. The charge of ore is about 11½ tons. Broken stone or poor solera ore is filled in, first, on the perforated arch, to a thickness of about 16 inches, and the richer ore, first china and then metal, is charged upon this. The bacisco is put in last, and the charging openings are then closely luted up. A fire is next lighted below, and is kept up for eight or ten hours, consuming 2·2 to 2·5 tons of wood. The ore is then sufficiently kindled, and the fire is let out; but the mass of ore is maintained at a red heat by the combustion of the sulphur that it contains, and continues to calcine spontaneously, until this and the mercury combined with it have been expelled. The residue is then allowed to cool, and is discharged, and a fresh charge is put in. Each operation lasts seventy-two to seventy-five hours, thus divided; charging, one hour; firing, eight to ten hours; calcination, forty-five to forty-six hours; cooling, eighteen hours.

The mercury condenses chiefly in the portion of each row of aludels nearest to the furnace, and flows from the aludels through openings 2 to 4 mm. in diameter in the under side of each, into suitably arranged gutters, and thence into a reservoir. The aludels nearer to the furnace are taken up at intervals of fifteen days, and those more distant every two months, to clear out the mercurial dust or soot that gathers in them.

The Idrian furnaces, of which there are only two at Almaden, differ from the Bustamente furnaces in little except their greater size, and the form and arrangement of the condensers. The furnace is 3 metres in inside diameter by 7·50 metres high, and the fireplace is separated, as in the Bustamante furnace, from the chamber that receives the charge by an arch of perforated brickwork. Each furnace communicates with twelve masonry condensing chambers arranged in two series of six. The condensers are lined with Portland cement, and the mercury from them is led by pipes into a stone reservoir. The charge is between 28 and 29 tons, and each operation lasts six days; one for cleaning and charging, one for firing, two for calcination, one for cooling, and one for discharging.

The mercury is led from each furnace to the magazine by a wrought-iron pipe, and is there put up for sale in wrought-iron bottles containing each 34·507 kilos., or 75 Castilian pounds of the metal.

The loss of mercury in the process of distillation has been determined with great care, and does not exceed 5 per cent. of the quantity contained in the ore treated, in the case of the Bustamante furnace, or 5·5 to 6 per cent. in that of the Idrian furnace.

The deposits of mercury in the United States are rich and extensive, they have been described by Dr. T. Egleston, and the following particulars are upon his authority.

The ores of mercury which are found in California are metallic mercury and cinnabar. They occur in large quantities, and both of them are mined and treated as ores. Minerals of mercury occur occasionally, such as the selenides, but they are rarely found, and have no metallurgical interest. Cinnabar is generally found near the junction of serpentine and sandstone.

Sometimes ore is found in clay, as at the Sunderland Mine, and upon Mount Shasta, where it occurs in seams of clay. At the Geyser, New Almaden, Gaudalupe, and the outcrop of the Oakland mines, the serpentine is very much decomposed on the outside. The decomposition goes so far into the rock that it is only in the large pieces that its real nature can be seen. This decomposition is going on still in all the mines in the serpentine, the waters from which, and from the surrounding country, contain large quantities of sulphate of magnesia.

The sandstone is sometimes very fine and soft, and forms what is called the mud rock. At the Oceanic Mine the sandstone is so crumbly that it falls easily to powder on being worked, so that nearly all the ore has to be made up into adobes, to which mud has to be added to hold it together. Where the sandstone is not decomposed, it very often contains considerable quantities of petroleum, which renders the extraction of the ore more difficult by increasing the amount of soot.

These ores, especially those in the sandstones, are often found associated with chalcedony. But these masses are very irregular in the mine. The rock is sometimes rich enough to yield 3 to 10 per cent., and sometimes more, of mercury. A microscopic examination of this chalcedony containing cinnabar, shows that the cinnabar is crystallized, the crystals being in a great many cases doubly terminated, though to the eye nothing but a red stain is perceptible.

As the serpentine rock is very susceptible of decomposition, it has often been thoroughly decomposed on its outcrop to a very considerable depth. Where the serpentine has formed cliffs it has been washed into the valleys, so that there is a large deposit of material from the decomposed rocks. In such cases it will be found that what appears to be nothing more than ordinary dirt will contain frequently from 2 to 3 per cent. of metallic mercury, with only a trace of cinnabar; in which case it is made up into adobes and distilled. Not unfrequently the outcrop of the rock where it is not decomposed is filled with metallic mercury, so that by striking a pick into the rock, a pound or more of mercury will sometimes spurt out at a time. Such rock as this is found in several localities in every stage of impregnation, from mere microscopic globules up to those yielding large quantities of it, which makes very rich ore; there is, however, not very much of it in any one place

It consequently cannot be depended upon, as it is only found in the first workings. The ore in depth is always cinnabar.

At the Sulphur Bank Mine in Lake County, the ore is found in an extinct geyser which still produces boiling water, associated with very large quantities of gypsum and sulphur, directly on the shore of the lake. Sometimes there is more sulphur than cinnabar, which is a detriment to both sulphur and cinnabar, making the sulphur impure, and rendering the cinnabar difficult to work on account of the soot. In some of the early constructed furnaces, the accumulation of soot from the excess of sulphur has been known to penetrate as far as the blower, and completely prevent its revolution. In order to get rid of the inconvenience of this accumulation of soot, as well as to get a commercial value from the sulphur, it is now separated by steam and sold. The ore is mined in an open cut, and in several places they have reached the lake level. Besides the rich ore there is a very large quantity of poorer ore yielding 1 or 2 per cent., which the sulphur makes almost impossible to work. As the sulphur is in such large quantities, it is very necessary that the work should be done without fire, the use of which is strictly forbidden to the workmen.

The ore is divided into two separate categories, that containing a large and that containing a small quantity of sulphur. That containing a large amount is first treated for sulphur in a steam-furnace. The upper part, which is round, is made of thick boiler plate bolted on to a cast-iron bottom. The charging door is hinged, and screwed down with a handle. The lower part is provided with a heavy cast-iron grate, on which the ore rests. The ore is charged upon the grate and the furnace closed. Steam at the temperature of 230°, and at a pressure of 50 lb., is introduced, the sulphur is melted, liquates, and runs through the grate into the lower part, from which it is discharged by means of the stop-cock, which is surrounded by a steam jacket to keep it hot. When no more sulphur flows the discharge door is opened, and the residue is treated for mercury.

The attempt to concentrate the poorer ore has been made with more or less success, with the Frue Vanning machine. The results of these concentrations are treated in retorts, of which there are fifteen or twenty. The fine ore is treated in a furnace somewhat similar to the old Idrian furnace, but as it is used for fine ore it is made to fall over triangular shelves made of tile, and arranged somewhat similarly to the Gerstenhoffer furnace. The condensers are arranged as in the old Idrian furnace, although they are continuous. The furnace treats 12 to 13 tons in twenty-four hours.

Generally the ore, as it comes from the mines, is more or less hand-picked. The attempts which have been made to treat the ores mechanically have usually not been successful, and no attempt is made to concentrate the ore. It is taken as it comes from the mines, and if it contains binding material it is made up into adobes; if it does not contain any, some must be mixed with it. The adobes have no regular size or weight, and are treated in the furnace as large ore.

The metallurgy of mercury in California is essentially different from that employed in all other countries in this respect, that all the furnaces use fans placed beyond the condensing apparatus, to furnish their draught; this plan not only gives an absolute control of the draught, but avoids the necessity of employing chimneys, and prevents the action of the fumes on the surrounding life and vegetation. The consequence of this arrangement is, that the draught is always towards the interior of the furnace or condensing apparatus, so that if a crack appears, or a door is left open, no fumes will escape; cases of salivation are consequently very rare. The draught can always be regulated to suit the working of the furnace, or the irregularities of the weather, by changing the velocity of the fan. In all of these methods the furnace itself is of very much less consequence than the condensing apparatus, though it should always aim to extract the metal from the ore at the lowest possible temperature, and to be able to work the ore required after the least possible mechanical preparation. It is consequently on the condensing apparatus, rather than on the furnace itself, that the greatest number of experiments have been made. Of these furnaces, the one which has the best condensing apparatus will be the best.

The processes by which the ore is treated are, first, the process of precipitation; second, that of roasting. The precipitation is done in retorts with lime, and consists of admitting oxygen enough, by means of an excess of air, to produce sulphate of lime and free mercury. The roasting is either done in continuous or non-continuous furnaces which are either retorts, or various kinds of shaft furnaces. The reaction, as the ore always contains more or less moisture, consists in volatilizing the sulphur, and oxidizing it so as to produce sulphuric acid, which is taken up with the moisture, and runs to waste, while the mercury becomes free, and is caught in condensers. The furnaces, which are not continuous, are a modification of the old Idrian furnace. Those which are continuous are the Lockhart and the Livermore furnaces, the latter adapted only for treating fine ores.

There are a great many varieties of shaft furnaces which are continuous, some of which work with water jackets.

The only effort made to sort the ore is a rough attempt at hand-picking. It is generally assorted into approximate sizes, over rudely constructed gratings, the object of which is to separate the fine ore as much as possible, since most of the furnaces would be clogged if fine ore in any proportion were allowed to enter them. No assays are made; there is consequently very little dependence to be placed upon any of the statements of the advocates of the different kinds of furnaces, that their furnaces actually yield a higher percentage than those of their neighbours, or, in fact, that they yield any given percentage at all. The only statement that can be relied upon is, that they produce in twenty-four hours a given number of pounds of mercury. The mercury is delivered to the market in iron flasks, which contain 76½ lb. each. It is accurately weighed in a balance constructed for the purpose, and poured into the flasks. They are closed with an iron screw for a cork, which is screwed tight with a long lever, and then shipped to the consumer. When the flask contains more or less than this, it is called an irregular flask.

METERS.

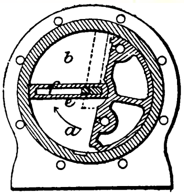
Water meters may be divided into two distinct varieties; low-pressure and high-pressure meters. The first are represented as a class by those which discharge definite quantities of water, by successive and intermittent actions, out of measuring chambers of known capacity, into cisterns situated underneath for its reception, the mere weight of the water being generally employed as the moving agency.

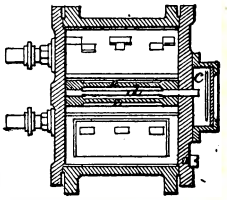
The high pressure class delivers the water at higher levels than those of the meters themselves, and are impelled in some cases by the mere velocity of the current of water passing through them, but in most instances by the pressure alone.

In Reid's meter, instead of employing the ordinary form of piston, there is a light and easy fitting metallic piston of a rectangular shape, revolving on one of its edges around the axis of a short cylinder, while its opposite edge sweeps the inner circumference of the cylinder, and moving so freely that a few inches of water pressure is sufficient for its impulse.

Figs. 1751 and 1752 are vertical sections at right angles of the instrument. The measuring chamber *a b* is a cylindrical segment, rather larger than a half-circle; the index *d*, within a glass-fronted box *c*, and the counter-wheels are acted on by the revolving spindle. The piston *e* is rectangular, and is connected to the spindle passing through a slot *f* in the piston, as in Fig. 1751. One edge of the piston *e* works in contact with the inner surface of the cylinder, whilst the opposite edge works into a concentric cylindrical cavity of smaller radius formed in the chord side of the chamber. The chord side is vertical or inclined, the inlet for the liquid is below the central cavity, and the outlet is above it. When the piston is in the position shown, the liquid entering below lifts it upwards and round the course till nearly parallel with the chord, at which time the lower edge of the piston escapes from the central cavity, and slides down by gravitation over or through the spindle, thus translating the axis of revolution from one end of the piston to the other, when it again ascends by the pressure of the inlet from below, while the liquid above is forced outwards by ascending through the outlet port above. The opposite sides of the piston at the ends are slightly bevelled off, to ensure the piston sliding down just before it comes in contact with the chord surface.

1751.

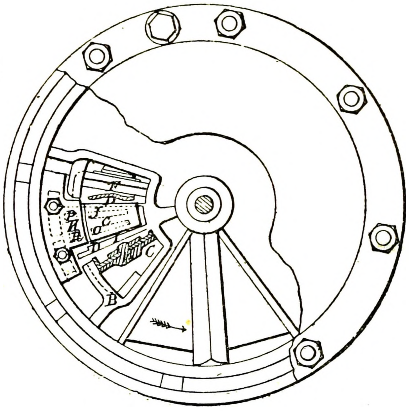




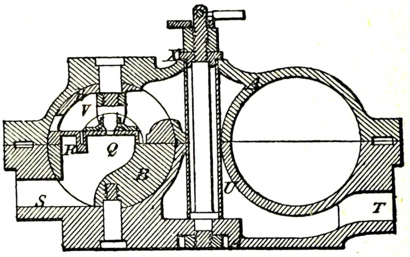
1752.

The piston meter, Fig. 1753, and to a smaller scale in section, Fig. 1754, invented by S. Hannah, of Darlington, consists of two cylinders, with pistons, which actuate each other's slide valves. The larger of these chambers forms the body of the meter A A; the smaller, B B, forms the valve chest, and is fixed within the other, the whole being made in halves which are bolted together at the centre and edges. The side wings of the valve chest contain the small chamber, while its centre is occupied by the valves and ports. All the ports open up on one level face flush with the main joint. The small piston valve E F is double-ended, and carries the main slide valve *c*. The secondary slide valve K is provided with two bent arms passing through openings in the valve face, which are covered water-tight by the valve. These two arms, whose positions are shown by their nuts on the valve, are bent outward under the face, and are pushed alternately by the main piston at the ends of its stroke. The index is of the usual gas-meter form, taking its motion from the main piston by means of a ratchet. Water entering at T passes twice through the cylindrical perforated strainer U, which can be removed for cleaning at any time on taking off the top nut, to the valve chest, filling the space V between the two ends of the small piston. There is thus an equal and constant pressure on the inside of both ends of it, its motion being caused by the disturbance of equilibrium, when one end of its chamber is connected with the supply and the other with the exhaust. From this chamber the water is distributed by the slide valves *c* and K through the ports I J and P D, to the main and secondary chambers alternately, and is ultimately exhausted through the centre ports Q R, which unite to form the outlet S. The action is as follows;—The main piston, when in the act of completing its stroke, pushes the secondary slide valve K into its reverse position. The secondary piston then makes a stroke, carrying with it the main slide valve *c*, and this reversing of the main slide causes the return motion of the main piston.

1753.



1754.

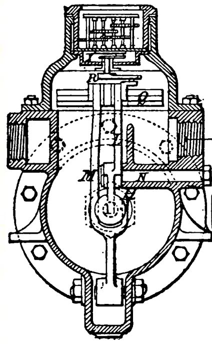


The meter, Figs. 1755 and 1756, consists of two cylinders and pistons, end to end on the same axis, the cylinders being separated by a narrow space, in which the levers for working the slide valves are placed. The whole of the meter, excepting the two cylinder covers and the valve jacket, is in one casting. The water is admitted to and expelled from both sides of each piston alternately, and each piston works, by means of levers, the slide valve of its opposite cylinder.

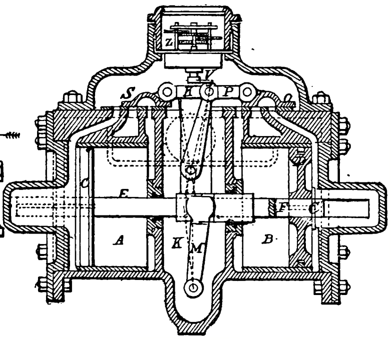
Each piston must travel to the end of its stroke, and empty the total capacity of its cylinder, before the other cylinder can receive its complement of water.

Fig. 1756 is a longitudinal section, with one piston and rod in elevation, and the other in part section. Fig. 1755 is a cross-section through the level chamber. Fig. 1757 is a plan of the valve faces and the like. A B are the two cylinders bushed with gun-metal, and bored out truly with each other by the same boring bar. C D are the pistons of cast iron with metallic packing rings, which are preferred for this purpose. The piston rods E and F are of gun-metal, and are independent of each other, but the end of F is increased in diameter and bored out to receive the end of E, which works freely in it. The pistons have a long boss, in which the rods work freely, and, as the end of the boss is solid, no water can pass from one side of the piston to the other. The rods are slotted out as in Fig. 1755, and the pistons have a steel pin G secured through their boss, which, after the piston has travelled for a portion of its stroke, strikes the end of the slot, and works the valve motion. Gun-metal bushes H H are screwed into the inner ends of the cylinders A B, and leather collars are inserted through which the piston rods work. The leathers are kept in position by screwed nuts. In the chamber K two gun-metal levers L and M are fixed, to oscillate on their respective studs N and O. The piston-rod E has a slot near its end to receive the extremity of the lever L, and the rod F has its two sides flattened to form shoulders for the forked lever M. The lever L is connected by the link P to the slide valve Q, and the lever M by the link R to the valve S. The valves are of the ordinary D shape, and, as well as their faces, are of gun-metal. The levers are proportioned so as to give to the valves their proper amount of travel. On the top of one of the links a projecting stud or pin is formed, giving motion to a lever pinned on to the end of a spindle V, which passes through the stuffing-box into the bottom of the box X. On the other end of this spindle a ratchet with spring is fixed, and works into a ratchet wheel, secured on the main spindle of a counter-gear, enclosed in a water-tight box Z screwed into a recess cast on the top of the valve casing. The counter-gear is similar in all sizes of the meters, with the exception of the ratchet wheel, which is varied as to the number of teeth to suit the registry of the various sized meters. These meters are very compact, the size with a 1-in. delivery only occupying a space of about 15 in. by 14 in. deep over the index box. A meter having cylinders $4\frac{3}{4}$ in. diameter, with a 2-in. stroke, delivers from 2300 to 2700 gallons an hour. It is stated that they can be worked under any pressure, and have been found to register equally correct under 50 lb. a sq. in., and under a few inches head of water.

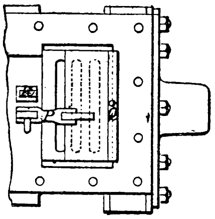
1755.



1756.



1757.



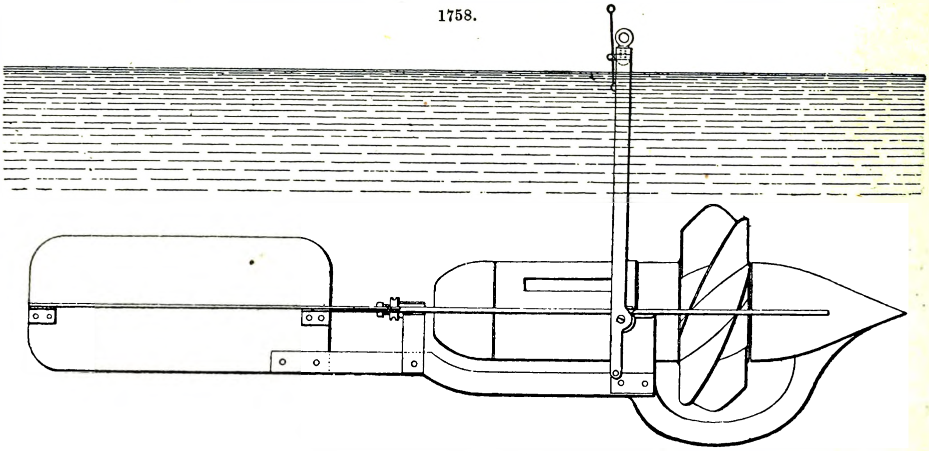
In the current meter designed by B. T. Moore, the two main features are the frame, which is so constructed as to secure the required position of the instrument in running water; and the rotating cylinder, containing the internal mechanism for recording the number of revolutions made in a given time. The instrument can be lowered into water to the required depth by a light chain or cord from a boat or other platform, and the rotating cylinder can be set in action or stopped at any instant while under water. When the current meter is lowered into running water it takes up a definite position with respect to the direction of the stream, and steadily maintains that position, no apparatus being required to fix it. Fig. 1758 is a side elevation of the instrument, and Fig. 1759 a plan of the frame with a section of the revolving cylinder, showing the mechanism within it. Figs. 1760, 1761, and 1762 are transverse sections of the revolving cylinder. The frame consists mainly of three flat thin bars of brass, united to the solid ogival head which forms the front of the instrument, and terminating in a long double tail or rudder, the section of which is a cross with equal arms. They are bound together to form a stiff and strong frame, but so as to offer the least possible resistance to running water.

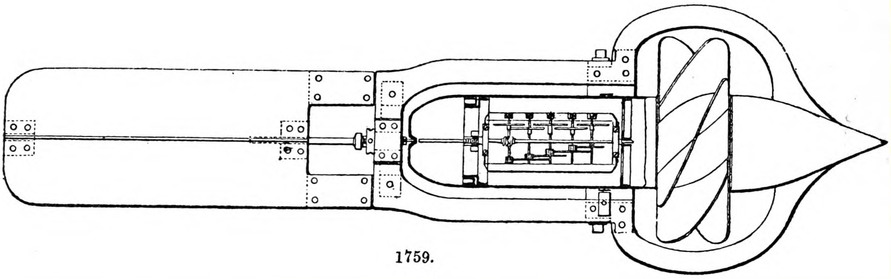
The frame is suspended from a stirrup by two bearings, the geometrical axis of which is perpendicular to the longitudinal axis of the frame, which passes through the point of the ogival head and the line of intersection of the plates of the double tail; and the sides of this stirrup are extended downwards, and pierced with two holes for the purpose of attaching a lead weight to keep the instrument in place when used in a rapid stream.

The rotating cylinder is immediately behind the ogival head, having its axis coincident with the longitudinal axis of the frame. The centre of gravity of the whole instrument is in the geometrical axis of the bearings by which the instrument is suspended from the stirrup, and midway between them.

The instrument is symmetrical about a vertical plane through the longitudinal axis, and, with the exception of the keel plate, about a horizontal plane through the same axis. Thus, when the current meter is lowered into running water by a cord attached to the swivel at the top of the stirrup, the stream, acting upon the double rudder, will bring the longitudinal axis of the instrument in the direction of the current, with the ogival head pointing accurately up the stream, and this position of the instrument will hold good however great may be the velocity of the stream; for the vertical line through the centre of gravity, the direction of the pull upon the stirrup, and the resultant pressure of the running water upon the instrument, all pass through one point, and are in equilibrium, and consequently no couple is brought into action to turn the instrument out of the required position.

1758.



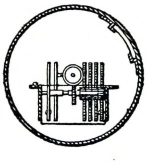


1759.

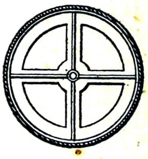
This does not take into account the action of the water on the keel plate, which produces a couple of small moment tending to raise the tail of the instrument; but this tendency is easily corrected by giving a slight inclination upwards to the horizontal plate of the tail, which calls into action a couple of equal moment in the opposite direction, and thus the axis of the instrument is kept in the direction of the stream.

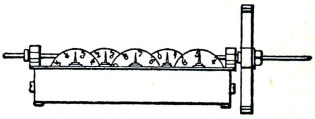
The cylinder is set in rotation, or stopped, by operating on the spring which is fixed to the frame and partly embraces the cylinder. A light cord attached to the spring passes, side by side with the cord which suspends the instrument, to the hand of the operator; by raising the cord a few inches, until it is tight, the spring is lifted and the cylinder is released, and when the cord is let go the spring is set free and again engages the cylinder. It is convenient to pass this cord through small rings upon the main cord at intervals of 1 ft.; thus all chance of the stream lifting the spring is avoided, and the rings serve to measure the depth to which the instrument is lowered. The cylinder is set in motion, when free, by the action of the running water on the screw blades fixed to it.

1760.



1761.





1762.

In the instrument, Figs. 1758 and 1759, the recording mechanism is placed inside the rotating cylinder, which is water-tight and contains a strip of glass so placed that the mechanism can be clearly seen through it. In other instruments the mechanism is enclosed within a water-tight tube of glass, which slides in and out of the rotating cylinder. The tube is closed by two brass discs connected together by a thin steel spindle, the axis of which coincides with that of the tube and cylinder; this spindle is screwed at its ends into the discs, by which means they are drawn close to the ends of the glass tube, and the joints are made water-tight by thin rings of leather. When the cylinder containing the glass tube is set in rotation, the small steel spindle also revolves about its own axis. From this spindle is suspended a small rectangular brass frame, having holes at the ends through which the spindle passes. The frame contains a simple train of wheels connected by a worm-wheel with an endless screw upon the spindle, the centre of gravity of the frame and wheels being below the axis of the spindle; consequently, when the spindle revolves the frame remains at rest, or oscillates very slightly, and motion is set up in the train of wheels, and the revolutions of the cylinder are recorded by graduated dials revolving with the wheels. There is no stuffing-box, stiff joint, or bearing, in any part of the instrument. The resistances of the working parts are extremely small, and the cylinder may be made to revolve with a velocity much greater than that due to any running water without fear of the suspended frame tripping or turning over. The rotating cylinder being hollow and water-tight in some instruments, and containing a water-tight glass tube in others, is supported by the water to the extent of the weight of the water displaced, the difference between its weight in water and in air being the weight upon the bearings. This resulting weight is less than 1 oz. in some of the lighter instruments, and in the heavier instruments, containing the glass tube, it gives an average pressure on each bearing of about 5 oz.; and as the bearings are less than $\frac{1}{16}$ in. in diameter, the frictional resistance which they offer to the motion of the cylinder is extremely small. Moreover, the instrument is far more sensitive to the action of running water than would at first appear, because the weight of the rotating cylinder and its contents is twice as great in air as in water, being on an average 10 oz. in water and 21 oz. in air.

The friction of the internal mechanism within the glass cylinder is constant and wholly unaffected by the velocity of the stream. This mechanism is lubricated by oil, which seldom requires to be renewed.

The friction on the front external bearing is also constant, as this bearing only supports one end of the cylinder and sustains no thrust; the weight upon it is about 6 oz. The friction on the back bearing, which also acts as a pivot, is the only variable friction in any working part. This pivot has to sustain the thrust caused by the action of the running water on the screw blades only, there being no thrust due to the running water on the front end of the cylinder, because that is protected by the solid ogival head which forms the front of the frame. Thus the only variable friction is that due to the pressure on the back pivot. The moment of the resistance due to this friction is proportional to the product of the pressure and the radius of the pivot. This radius being less than $\frac{1}{32}$ in., while the effective radius of the screw blades is not far short of 2 in., the ratio which this moment of resistance bears to the driving moment caused by the action of the running water on the screw blades is extremely small, and consequently the variable resistance of this pivot will not be sensible in practice; thus the friction of the working parts is for all practical purposes a constant quantity. The bearings upon which the cylinder rotates are the only bearings exposed to water. They are made of steel, nickel-plated, and are lubricated by the water in which the instrument works.

The rate of the instrument was obtained by drawing it several times through still water, for a known distance, at different velocities, for which purpose it was attached to, and underneath, a float about 6 ft. in length. By comparing a number of results obtained in this way the formula

$$V = 1{\cdot}2\,R + Q,$$

was arrived at, where V is the velocity of the instrument through the water in feet a minute, or the velocity of the water with respect to the instrument; R the number of revolutions of the cylinder a minute, and Q a quantity which vanishes when R is equal to or greater than 60, and increases, as R diminishes, in the ratio of 1 to 5, the general value of Q being $\frac{60 - R}{5}$,

$$\therefore\ V = 1{\cdot}2\,R + \frac{60 - R}{5} = 1{\cdot}2\,R + 12 - {\cdot}2\,R = R + 12,$$

for values of R less than 60, and

$$V = 1{\cdot}2\,R$$

for values of R greater than 60.

From this it follows that when the velocity of the stream is 12 ft. a minute, the rotating cylinder is bordering upon motion, its moment of inertia being just balanced by the moment of the force due to the action of the running water on the screw blades.

The instrument will not measure a smaller velocity than 12 ft. a minute when it is suspended from a boat at anchor, or from a fixed platform; but smaller velocities may be measured by it if drawn, with a known velocity, against the current. Thus, if the instrument be drawn with a velocity of 20 ft. a minute against a stream whose velocity is V, and the number of revolutions be 14,

$$20 + V = 14 + 12 = 26, \text{ and } \therefore V = 6.$$

In this way very small velocities may be measured.

The current meter, when in use, is always drawn back by the stream through a small distance, from the vertical line passing through the point of suspension, the amount increasing with the velocity of the stream and the depth to which the instrument is immersed. This distance is greatest when the rotating cylinder is at rest, because the screw blades, being then fixed, offer greater resistance to the water. When the cylinder is set free, by raising the spring, the resistance is diminished, and the instrument advances through a small distance to meet the stream. This advance will tend to increase the number of revolutions of the cylinder in a given time, but on the other hand, it is equivalent to a momentary quickening of the stream, which helps to overcome the inertia of the cylinder and to set it in full rotation quicker than would otherwise be the case. But the greatest error which could arise from this advance of the instrument is extremely small, compared with the whole number of revolutions made in a given time; by allowing the instrument to remain some minutes under water, this small error is distributed over the whole number of turns, and becomes practically inappreciable. The vertical depth of the instrument below the surface is also affected by the distance through which it is drawn back by the stream, but this error in the depth would be only a small fraction of the horizontal distance, and consequently it would not be necessary, even if it were possible, to take it into account.

To use the instrument, the stirrup is put back upon the frame and the latter raised to the level of the eyes, the tail being held with the right hand, and the pointed head with the left. The dials will then be seen through the glass, and their reading must be taken down. The instrument is next to be lowered into the water, started and stopped at known instants by the spring, then drawn up out of the water, and the reading taken again. The difference between this and the former reading will give the number of revolutions in the time observed. In Fig. 1762, the frame which contains the mechanism is shown detached from the cylinder, the reading of the dials being 32,705.

The dials will record 100,000 revolutions of the cylinder, after which the same reading will recur. This number of revolutions is equivalent to 120,000 ft., or more than 22 miles. Thus the instrument might be left under water for eleven hours, in a stream running 2 miles an hour, before the dials would go through a complete period; and even if the period were overrun, a comparison of the readings, with an approximate estimate of the velocity of the stream, would immediately reveal the fact.

An important characteristic of this current meter is the rapidity with which it can be used. A velocity at any depth down to 20 ft. can be taken with ease in five minutes, allowing the instrument a run of four minutes under water; in other words, only 20 per cent. of the whole time is required for observing and recording the instrumental readings. By using two instruments together the time can be still further economized, and each instrument will remain a longer time under water.

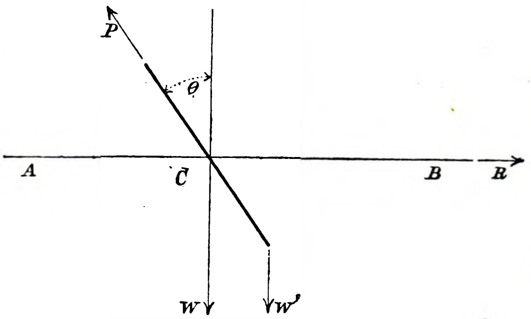
FORM OF FIELD BOOK FOR CURRENT METER.

$$\text{Rate of instrument, } 1\cdot 2 = \frac{\text{velocity in feet a minute}}{\text{number of revolutions a minute}}.$$

No. of Observation.	Times of Starting and Stopping.	Interval (min.).	Instrument Readings.	Differences.	Revolutions a Minute.	Velocity. Feet a Minute.	Mean adopted Velocity.	Remarks.
	H. M. S.							
1	3 2 15		23,714					
	3 5 15	3	23,927	213	71	85·2		
2	3 6 10		23,927					
	3 9 10	3	24,141	214	71·33	85·596	85·40	Station A.
3	3 11 20		24,141					
	3 15 20	4	24,513	372	93	111·6		
4	3 16 10		24,513					
	3 19 10	3	24,794	281	93·66	112·39	112	Station B.

In considering the mechanical principles on which the current meter is constructed, if A B, Fig. 1763, represents the axis of the instrument, A being the point of the ogival head, and B the extremity of the tail, and C its centre of gravity, B C is about three times the length of A C.

1763.



The forces which act upon the instrument are: W, its weight in water; R, the resistance which it offers to the stream; and P, the pull upon the stirrup, which inclines forward through some angle θ from the vertical.

These three forces, P, W, and R, are in equilibrium at the point C.

$\therefore$ P cos. θ = W, and P sin. θ = R.

The position of the axis A B is manifestly one of stable equilibrium when in the direction of the current; for if it be displaced about the point C, the action of the current will restore the axis to its former position. An increased velocity in the current increases R, and, therefore, both P and θ. This increase of θ can be prevented, when desired, by suspending a weight from the two ends of the stirrup.

Let W′ be the effect of this weight in the vertical direction, then the former of the above equations becomes

$$W + W' = P \cos.\ \theta.$$

Thus θ may be made as small as desired by sufficiently increasing W′.

ORES, MACHINES AND PROCESSES EMPLOYED TO DRESS.

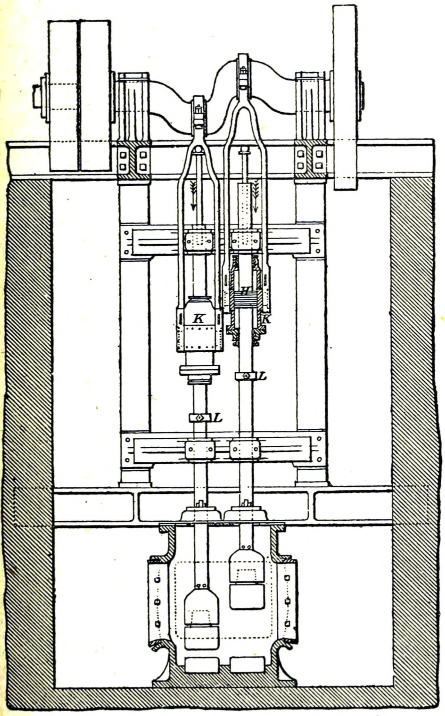
In dressing the tin ores of Cornwall, the object is to separate the ore itself, amounting to only from 1 to 2 per cent. of the whole stuff raised, from the large proportion of foreign mineral matter with which it is associated in the lodes. The ore of tin is a peroxide, which, when pure, contains 78·6 per cent. of metallic tin and 21·4 per cent. of oxygen. The impurities with which it is associated are mostly quartz, iron pyrites, commonly called mundic, yellow copper ore or copper pyrites, arsenic, sulphur, cobalt, and wolfram. The specific gravity of these minerals is shown in the following table, which is particularly interesting in consequence of the circumstance that the principle of dressing the ores consists, mainly, in separating the particles by taking advantage of their difference in specific gravity:—

	Specific gravity.		Specific gravity.
Sulphur	2·03	Arsenic	5·00
Quartz	3·00	Cobalt	5·00
Copper pyrites	4·25	Peroxide of tin	6·50 to 6·90
Iron pyrites, or mundic	4·90	Wolfram	7·00 to 7·50

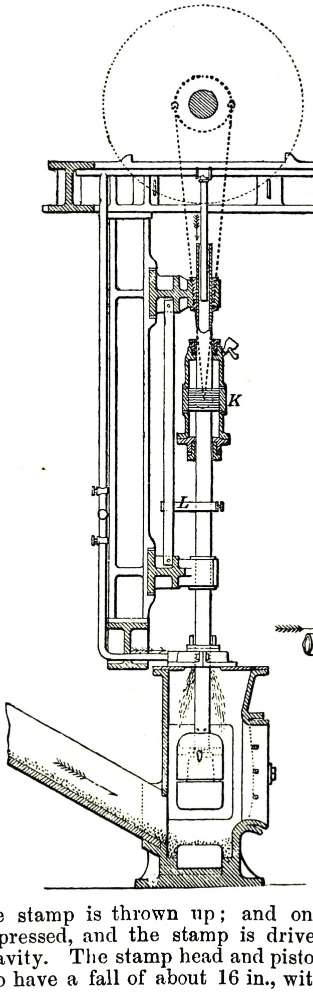
The stone that has been ragged and spalled is ready for the next process of stamping, in which it is crushed by stamps to a fine powder. The ordinary stamps, already described on pp 273 and 2527 of this Dictionary, are arranged in sets of four heads each, each cam shaft lifting sixteen heads or four sets; the number of heads depends upon the extent of the mine, and in some there are as many as twenty-five sets or one hundred heads. The disadvantage in the action of these stamps is that they produce a large proportion of slime, or material so very finely pulverized that much of it remains permanently mixed with the water throughout the subsequent process of separation, and thereby gets carried away as waste, though containing tin ore. The production of slime by the stamps is in consequence of their slow action allowing much of the pulverized material to settle down in the coffer and become further crushed to an unnecessarily fine powder, instead of passing out at once through the grates; and a quicker speed than fifty to seventy blows a minute cannot be obtained with the height of fall of these stamps.

Figs. 1764 to 1767 show Husband's pneumatic stamps, in which this difficulty has been met, by an ingenious arrangement for greatly increasing the rapidity of the blows, by the use of an air spring. The stamp head is not lifted direct, but is attached to a piston H working in an air cylinder K; and this cylinder has a reciprocating motion given to it by a crank shaft, through a forked connecting rod that is coupled to trunnions upon the cylinder. When the cylinder is raised by the crank, the air below the piston is compressed, and the stamp is thrown up; and on the crank turning the centre, the air above the piston is compressed, and the stamp is driven down with a velocity considerably greater than that due to gravity. The stamp head and piston rod, weighing together nearly 3 cwt., are by this means made to have a fall of about 16 in., with a stroke of only 10 in.

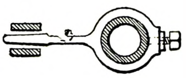
1764.

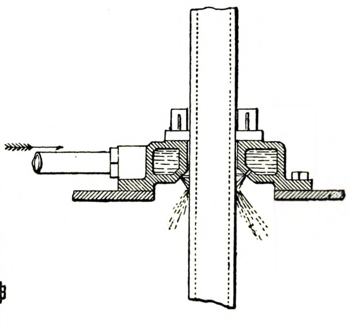


1765.



1766.



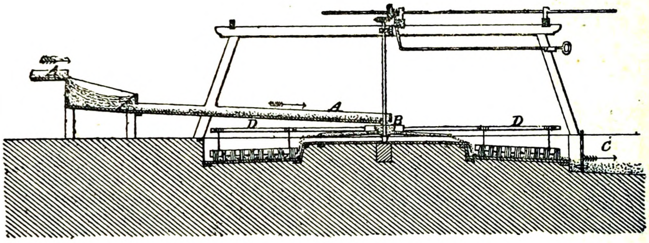


1767.

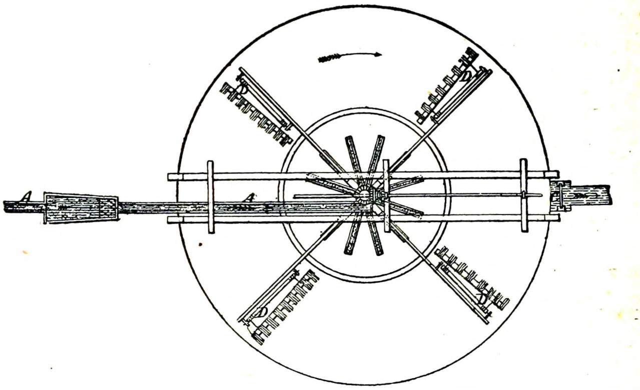
in the crank, and a speed of 150 blows a minute, in comparison with a fall of only 10 in. in the ordinary stamps, and a maximum speed of only 70 blows a minute. A ring of small holes is made all round the cylinder immediately above and below the centre position of the piston, as in Fig. 1764, so as to ensure both ends of the cylinder being filled at each stroke with air at atmospheric pressure. A continuous stream of water is made to flow through the hollow piston rod, for the purpose of preventing risk of heating by the compression of the air in the cylinder; this water is discharged through small holes at the bottom of the piston rod, just above the stamp head, and serves as part of the supply of water for the stamping operation. The main portion of the water supply to the stamp head is delivered in a circular jet, under a pressure of several feet head, upon the outside of the piston rod, where it passes through the cover of the coffer, Fig. 1767. In order to prevent the unequal wear of the stamp head, that would arise from the supply of fresh uncrushed stone being on one side only, an arrangement is made for turning the head round into different positions at regular intervals. This is done by a horn L fixed on the piston rod by a set screw, and working between two vertical guide bars, Fig. 1766; and about once a day the position of this horn is shifted so as to turn the piston rod partly round, and cause the stamp head to wear in a fresh place. These pneumatic stamps are erected in pairs, and stamp from 8 to 10 tons a head a day, in comparison with ¾ to 1 ton a head a day, the work of the ordinary stamps; the comparative consumption of coal a ton of ore stamped is also in favour of the pneumatic stamps. They have an important advantage in portability; and in the case of starting new mines, they can be readily transported from one point to another if found desirable, requiring but little foundation.

The form of buddle generally used in the first stage of the buddling process is shown in Figs. 1768 and 1769, and is known as the Convex or Centre-head Buddle. It consists of a circular pit, about 22 ft. diameter and from 1 to 1½ ft. deep at the circumference, with a raised centre 10 ft. diameter, and a floor falling towards the outer circle at a slope of about 1 in 30 for a length of 6 ft. The stuff is brought to the centre of the buddle in launders A, into which a constant stream of water flows; and it is distributed upon the raised centre from a revolving pan B carrying a number of spouts, so as to spread the liquid stream very uniformly in a thin film, which flows gradually outwards over the whole of the sloping floor to the circumference. In its passage down the slope the material held in suspension by the water is gradually deposited according to its specific gravity, and the tin ore being the heaviest is the first thrown down, and is consequently in greatest proportion towards the centre of the buddle. The outflow C for the waste and slime from the circumference of the buddle is regulated by a wood partition perforated with horizontal rows of holes, which are successively plugged up from the bottom as the height of the deposit in the buddle rises. To faciliate the uniform speading of the stuff over the floor of the buddle and prevent the formation of gutters or channels in the deposit, a set of revolving arms D are employed, from each of which is suspended a sweep carrying a number of brushes or small pieces of cloth, and these being drawn round on the surface of the deposit keep it to an even surface throughout; the distributing spouts and sweeps are driven at about five or six revolutions a minute. Figs. 1770 and 1771 are of Martin's buddle, in which the stream of stuff supplied to the buddle is itself made to drive the revolving centre pan and sweeps, the supply launder A delivering the stream upon a small water-wheel E geared to the pan B.

1768.



1769.



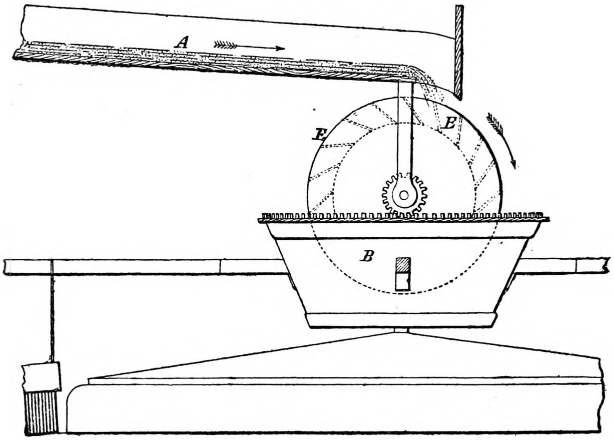
As the deposit accumulates in the buddle, the sweeps are successively raised to a corresponding extent; and the process is thus continued until the whole buddle is filled up to the top of the centre cone, which usually takes about ten hours. The contents are then divided into three concentric portions, each about a third of the whole breadth, which are called the head, middle, and tail; the head, or portion nearest the centre, contains about 70 per cent. of all the tin in the stuff supplied to the buddle, the middle nearly 20 per cent., and the tail, or portion next the circumference, contains only a trace; the remaining particles of tin are carried off by the water in the state of slime.

The heads from several buddles are then shovelled out, and thrown into a trough or launder, into which a stream of clear water flows, of sufficient quantity to convey the stuff to another buddle of different construction, the Concave Buddle, Figs. 1772 and 1773. The stuff is supplied at the centre of the buddle as before, but is conveyed from thence direct to the circumference, by revolving spouts that deliver it in a continuous stream upon a circular ledge, from which it flows uniformly over the conical floor, falling at a slope of about 1 in 12 towards the centre; it is kept uniformly distributed by means of revolving sweeps, as in the previous buddle. The greatest portion of the tin is in this case deposited round the circumference of the floor, and the slime and waste flow away through rows of holes in the sides of a centre wall; as the depth of deposit increases, the level of the overflow is gradually raised by plugging up these holes in succession.

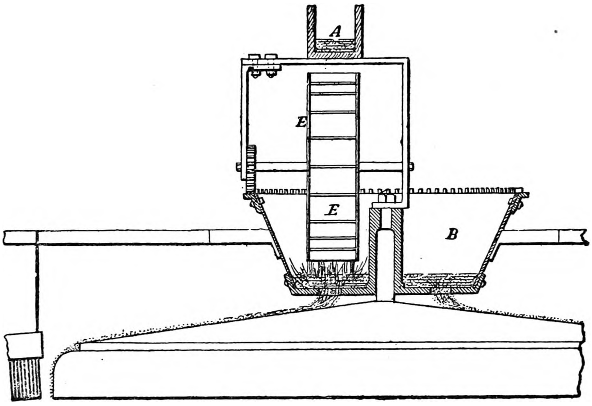
Figs. 1774 and 1775 show an improved construction of Concave Buddle by Edward Borlase, which has a mechanical arrangement for adjusting the level of the central outflow, by raising a ring R that slides upon the centre vertical shaft, as shown in the detail view to a larger scale. By this means the height of the outflow is adjusted more gradually and uniformly than by the plugged holes in the ordinary buddles, and there is less liability to waste by guttering. The sliding ring R is raised by hand by the rod I and lever L provided with the double adjusting nuts N; and the arms of the sweeps D being supported upon the rising ring are kept constantly at the proper height by the same adjustment. A mechanical agitator M at the head of the feeding launder stirs up the stuff before entering the buddle.

Another form of buddle is the Propeller Knife Buddle, Figs. 1776, 1777. It consists of a cylindrical frame, 9½ ft. long and 6 ft. diameter over all, rotating on a horizontal axis, and carrying a series of scrapers or knife-blades arranged in spiral lines round its circumference, which revolve close to a cylindrical casing lined with sheet iron, but without touching it; the casing forms the bottom of the buddle, and extends rather less than one-quarter round the circumference of the revolving frame, as shown in Fig. 1777. The tinstuff is supplied at one end of the buddle from the hopper A, and is made to traverse gradually along the whole

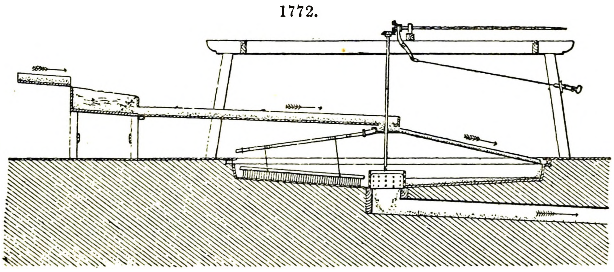
1770.



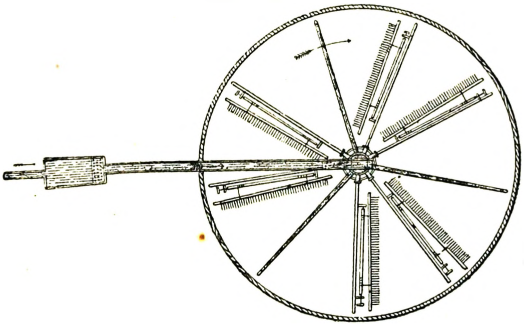
1771.



1772.



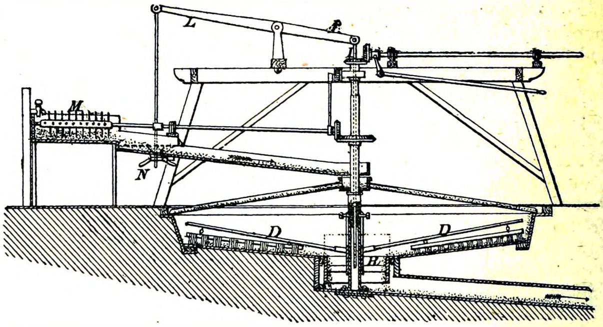
1773.



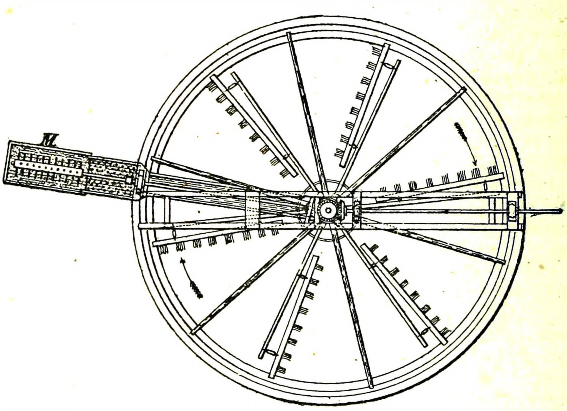
length to the other end by the propelling action of the revolving knives, which are fixed obliquely, and follow one another in spiral lines round the cylindrical frame. A gentle stream of clear water flows down over the whole curved surface of the bottom of the buddle, and the minerals are gradually propelled to the farther end, where they drop over the edge into the receptacle E. The machine is driven at about 20 revolutions a minute, giving the knife-blades a speed of about 370 ft. a minute. The action of this machine is found to be very perfect, the whole of the stuff being continually turned over by the knife-blades and pushed upwards against the descending stream of water, which washes out the lighter particles; the result is an unusually complete separation of the tin ore, in a single operation, with only a small proportion of loss in the waste. The contents of the second waste hutch D, are so poor as not to pay for any further dressing; and the waste in the first hutch C, containing a small proportion of slime tin, is passed through the buddle a second time.

The process of buddling is repeated three or four times in successive buddles, for further separating the foreign matter from the tinstuff, and the latter is then subjected to the process called tossing. It is put into a tub or kieve, about $3\frac{1}{2}$ ft. diameter and $2\frac{1}{2}$ ft. deep, and having been mixed with an equal bulk of water is then stirred up with a shovel continuously in one direction until the whole of the stuff is in a state of motion; the object is in this way to get rid of the finer particles of foreign matter, the buddling having separated all the heavy matrix. The stuff then undergoes the process called packing, which consists in tapping the side of the kieve with a heavy iron bar continuously for a period varying from a quarter of an hour to an hour; the bar is held vertically with one end resting on the ground, and with the upper end repeated blows of about 100 a minute are struck by hand against the edge of the kieve. This keeps up a constant gentle vibration in the contents and facilitates the separation of the tin ore, which gradually settles down to the bottom of the kieve. Instead of a bar worked by hand labour, a hammer worked by mechanical means is employed at some mines for performing the packing, with the advantage of maintaining com-

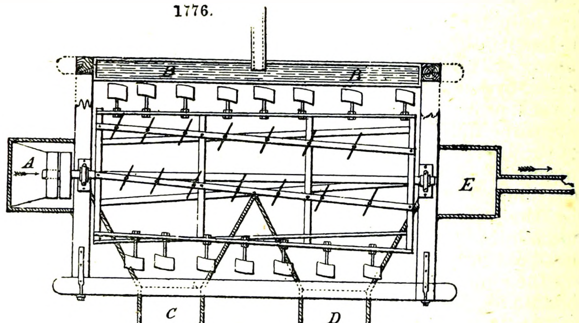
1774.

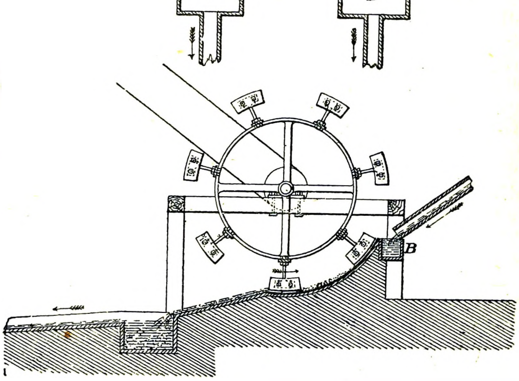


1775.



1776.



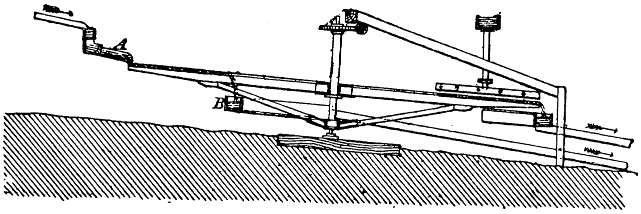


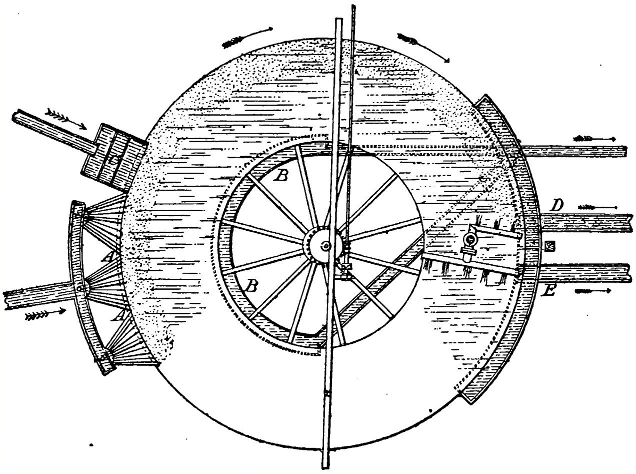
1777.

plete regularity in striking the blows for any length of time required. When the packing is finished, the upper portion of the stuff in the kieve is skimmed off and buddled over again, and the remainder, now called whits, is taken to the burning house to be calcined. The kieve is completely cleared out before being refilled with a fresh charge.

The ore-dressing machine of T. Borlase, shown in Figs. 1778, 1779, consists of a slowly revolving annular table, 24 ft. diameter and 6 ft. wide, placed at an inclination of 1 in 12 to the horizontal. The stuff to be dressed is supplied on the upper side of the table by a fluted spreader A, and the heavier or richer portion is deposited at once close to the circumference, while the poorer stuff is carried to the inner part of the annular table, and the waste runs off over the inner edge into the circular trough B underneath. A gentle stream of clean water supplied at C, immediately adjoining the spreader A, cleans the rich ore deposited near the circumference of the table, washing off into the centre space any of the waste that may have adhered to the table. At the lower side of the table jets of pure water wash off first into a receptacle D the outer ring of rich stuff, which extends about 2 ft. in from the outside ridge, and afterwards the inner and poorer portion, called craze, into a second receptacle E. The table makes one revolution in about three minutes, and in the half revolution from the upper to the lower side of the table, it is found that stuff originally containing $1\frac{1}{8}$ per cent. of tin ore is brought up to as much as 15 per cent. The richest stuff or whits, lying at the head of the first strip or tye D, is fit to be taken direct to the calciner, without requiring further dressing.

1778.

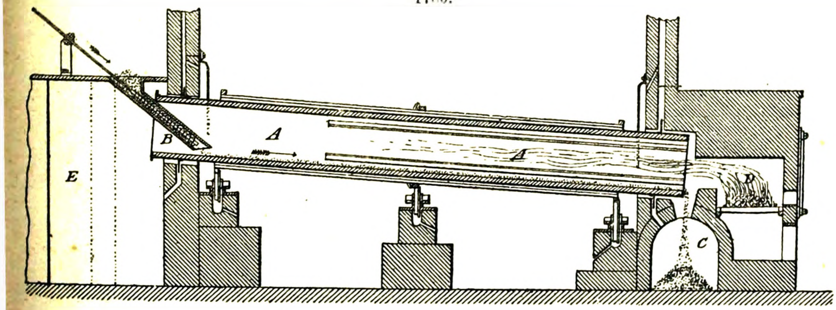




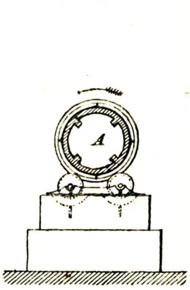
1779.

The next process is roasting or calcining the partially dressed tinstuff or whits, for the purpose of getting rid of the arsenic, sulphur, and other volatile impurities, and also to facilitate the subsequent removal of other foreign materials. Two kinds of calciners are now in use. The older one, known as Brunton's Calciner, consists of a revolving table, about 12 ft. diameter, enclosed in a shallow reverberatory furnace; the table is slightly conical in shape, its surface sloping downwards from the centre to the circumference. The tinstuff delivered on the centre of the table through a hopper in the roof of the furnace is exposed to the flame passing through the furnace, and is continuously stirred by a set of scrapers fixed in the roof whilst the table rotates very slowly below them, making only about six revolutions an hour. The scrapers being set obliquely shift the stuff gradually from the centre to the circumference of the table, where it falls off, and is collected in a chamber beneath.

1780.



1781.

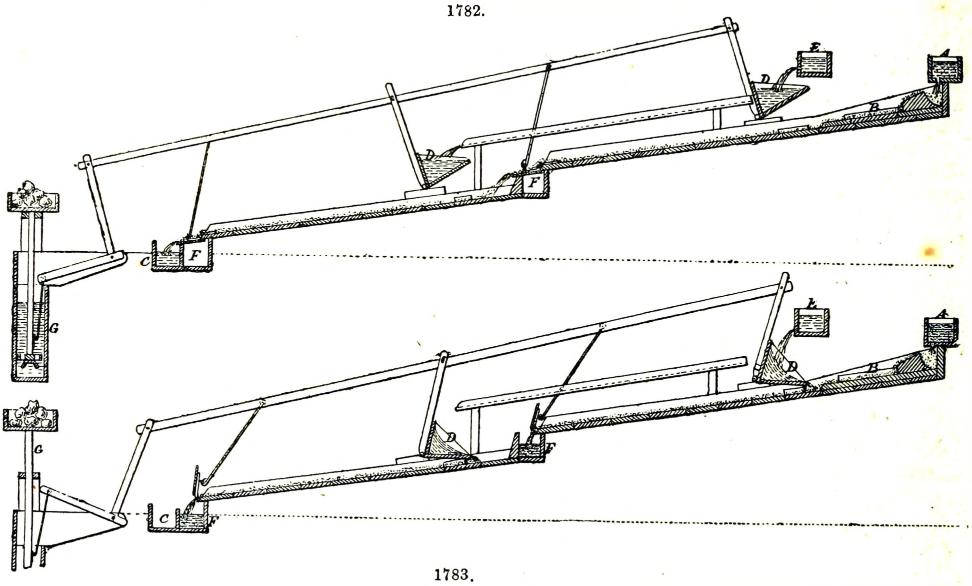


In Figs. 1780, 1781, is shown Oxlands and Hocking's Calciner, which is now adopted at several mines. It consists of a long wrought-iron cylinder A, lined with firebrick, 3 ft. inside diameter and 32 ft. long, placed at an inclination of 1 in 16 to 1 in 24, according to the nature of the stuff to be treated, and supported upon rollers, upon which it is made to revolve at a very slow speed of six or eight revolutions an hour. The tinstuff or whits is supplied into the higher end of the cylinder through a hopper fitted with a feeding screw B, and gradually traverses the length of the cylinder to the lower end, where it falls into a chamber C, from which it is removed for further treatment. The heating furnace D opens into the lower end of the cylinder, and the volatilized arsenic and sulphur are carried off by a flue E from the upper end; this flue is extended to a considerable distance, and divided by baffle walls into a succession of chambers, in which the arsenic is deposited and periodically collected. The time taken for the stuff to pass through the calciner is from three to six hours. The firebrick lining of the calciner is constructed with four longitudinal ribs projecting internally, as in the transverse section, Fig. 1781, and extending two-thirds of the length from the lower end, Fig. 1780; in the revolution of the calciner these have the effect of continuously stirring the stuff and exposing the whole of it to the heat. In this calciner the stuff being supplied at the upper end, farthest from the heating furnace, is exposed first to the lowest heat; and afterwards to a gradually increasing heat, as it works its way along to the hotter end of the calciner; by this means the most advantageous effect is obtained from the fuel consumed in the furnace. The stuff comes from the calciner in the state of a fine dry powder, which is cooled with water and taken again to the buddle; and the whole of the previous processes of buddling, tossing, and packing are again gone through and repeated a number of times, according to the quality of the ore, until this is finally in the condition ready for smelting; and it is then sold as black tin.

The whole process of dressing the tin ore for smelting occupies usually from eight to ten days, including the stamping; and the result obtained is an increase in the proportion of pure oxide or black tin from 1½ or 2 per cent. in the tinstone raised from the mine, up to 95 per cent. in the finally prepared ore that is sold for smelting. As tin dressing is only a process of separating by mechanical precipitation, a very small proportion of saleable produce from the large mass of mineral, through which it is disseminated in minute crystals, it is essential that the greatest precautions should be taken to prevent any waste of the valuable product. For instance, in buddling, the occurrence of any gutters or channels, down the sloping surface of the stuff in the buddles, would immediately cause the larger and more valuable grains of tin ore that are first deposited at the top of the slope, to be carried away with the water and slime. The grains of tin which do pass off with the slime, even from the best buddles, are very fine and light; and notwithstanding all the care that is taken in dressing the slimes, large quantities of tin ore are washed away from the dressing floors of the mines into the numerous streams and rivers of the district. The slimes are consequently intercepted at successive works on a stream or river coming from a series of mines, and large quantities of tin are collected by treating them in hand frames and concave buddles at a very small expense, the stream itself working a small water-wheel which drives the buddles, while the frames are attended only by a few children.

A simple form of self-acting slime frame or rack is that in Figs. 1782, 1783, by means of which the attendance requisite is so far reduced that one operator is able to attend to twenty frames. The launder A, bringing the slimes from the buddles, passes between two rows of the slime frames, set back to back, and the delivery to each frame is distributed by a fluted spreader B, as shown in the plan, Fig. 1784, and then flows uniformly in a gentle stream over the surface of the frame, which is at a slope of 1 in 7, and is divided at the middle into two halves by a 5-in. step; the waste flows off at the bottom of the frame into the launder C. The stuff deposited on the frame is then flushed off at successive intervals of a few minutes each, by a self-acting contrivance, consisting of two rocking troughs D D, which are gradually filled with clear water from a launder E; when full they overbalance, and discharge their whole contents suddenly upon the top of each half of the frame. The tipping movement of the troughs open at the same time the

1782.

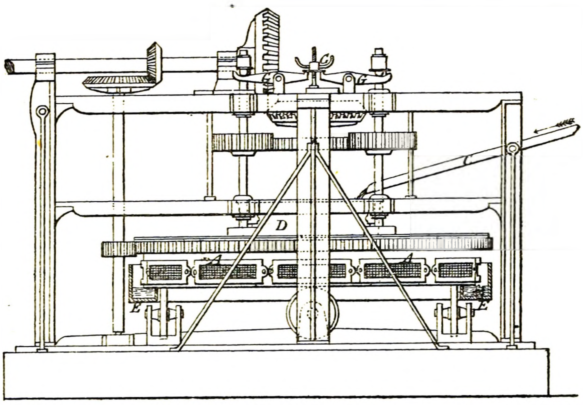


1783.

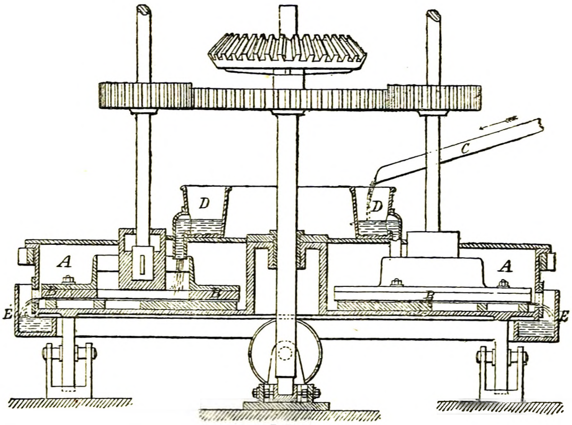
covers of two launders F F, one at the foot of each half of the frame, into which the stuff deposited on the frame is washed by the discharge of water, the two halves being kept separate, because the greater portion of the tin ore is retained on the upper half of the frame. The readjustment of the whole into the original position is effected by a cataract G, of simple construction.

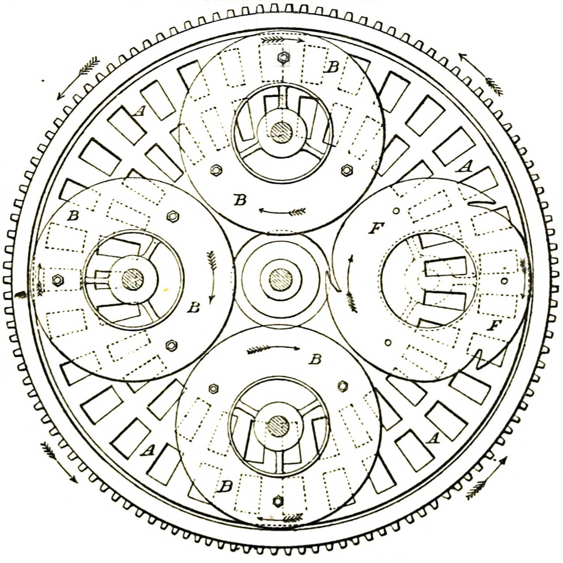
The difficulty in dealing with the slimes arises from the circumstance of the grains of tin ore being so minute compared with the particles of foreign matter with which they are mixed, that they are carried away in suspension by the water, in consequence of their extreme absolute lightness, although their specific gravity is greater than that of the larger particles of foreign matter they are mixed with. For the purpose of reducing these larger particles of foreign matter to the same size as the tin grains, and thereby enabling the latter to be separated by the ordinary dressing processes with water, several different machines called pulverizers have been introduced, having either a reciprocating or a rotary action; these have been found very successful in reducing the particles to a uniform size, and thus affording the means of utilizing the waste, or roughs as it is called, which was previously thrown away because the cost of reducing it by restamping was greater than the value of the tin ore obtained by such a process.

1784.



1785.





1786.

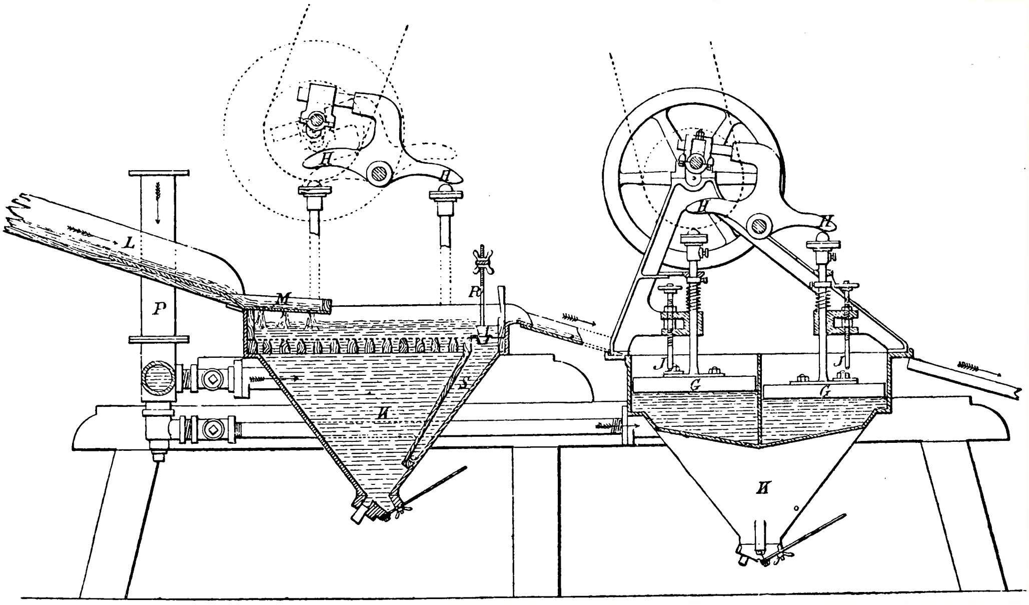
Figs. 1784 to 1786 are of Dingey's pulverizer. It consists of a shallow pan A of 6 ft. internal diameter, having vertical sides fitted with a series of grates, through which the pulverized material is delivered. Four annular grinding discs or runners B B, 2½ ft. diameter and geared together, revolve upon the bottom of the pan at a high speed of 200 revolutions a minute; and the pan itself is made to revolve slowly, at about 4 or 5 revolutions a minute, so as to avoid any tendency to wearing in grooves. The wearing surface of the bottom of the pan is a separate cast-iron plate, with a number of holes in it, Figs. 1785, 1786, forming shallow recesses, in which the stuff to be pulverized is retained whilst the grinding runners act upon it. The stuff mixed with a stream of water is supplied by a launder C into a central annular trough D, Fig. 1785, from which it is delivered by spouts into the centre of each of the grinding runners; and having been ground by passing under the runners, it escapes with the water through the gates in the sides of the pan into the external trough E, whence it is conveyed direct to the buddles. The shoes of the grinding runners as well as the bottom of the pan, are made separate castings, 1½ in. thick, so as to be readily replaced when required; at F, Fig. 1786, is shown a plan of one of the runner shoes. The space between the grinding faces of the shoes and the bottom of the pan, is adjusted by the hand regulating screws and levers G G supporting the runner spindles. The weight of the whole machine is about 4 tons, and it will grind from 15 to 20 tons a day of 24 hours, according to the class of stuff.

Copper ore is raised in the same manner as previously described with regard to tin ore, but it presents a marked contrast to tin ore in being very much less finely disseminated throughout the lodestuff with which it is associated; the coarser spots or patches in which it is met with necessitate consequently a very different treatment from that adopted in dressing tin ore. The most abundant ore of copper is copper pyrites, which is a sulphide of copper and iron, containing, when pure, only 34·6 per cent. of copper, with 30·5 per cent. of iron, and 34·9 per cent. of sulphur. The other principal ores of copper are the red, black, grey, purple, and green ores. The red and black ores are oxides, containing, when pure, 89 and 80 per cent. of copper respectively; the red, which is the more common of the two, is quite brittle, and is easily broken up into a red powder. Grey copper ore is a sulphide, containing, when pure, 80 per cent. of copper; it has much the appearance of metallic lead, but may be broken up by a hammer. Purple copper ore is a sulphide, but not so rich as the grey, part of the copper being replaced by iron; when pure it contains nearly 70 per cent. of copper. Green copper ore, or malachite, is a carbonate, and is much less common than any of the others; it contains, when pure, 57 per cent. of copper. None of these ores of copper are very hard, all being readily scratched with a knife.

The ore as raised from the mine is tipped into spaces called slides, in quantities averaging from 5 to 20 tons in each slide. The larger stones having been separated, and ragged or broken up into smaller pieces by hand hammers, the whole is passed through two revolving riddles of different mesh, and then hand-picked and sorted into three qualities—prills, or best; dradge, or second quality; and halvans, or leavings. As much of the best as will pass through a riddle of $\frac{3}{4}$-in. mesh is taken at once to the pile ready for market, and the rest goes to the crushing rolls to be crushed down smaller. The second quality has to undergo both crushing and jigging. See p. 2535 of this Dictionary.

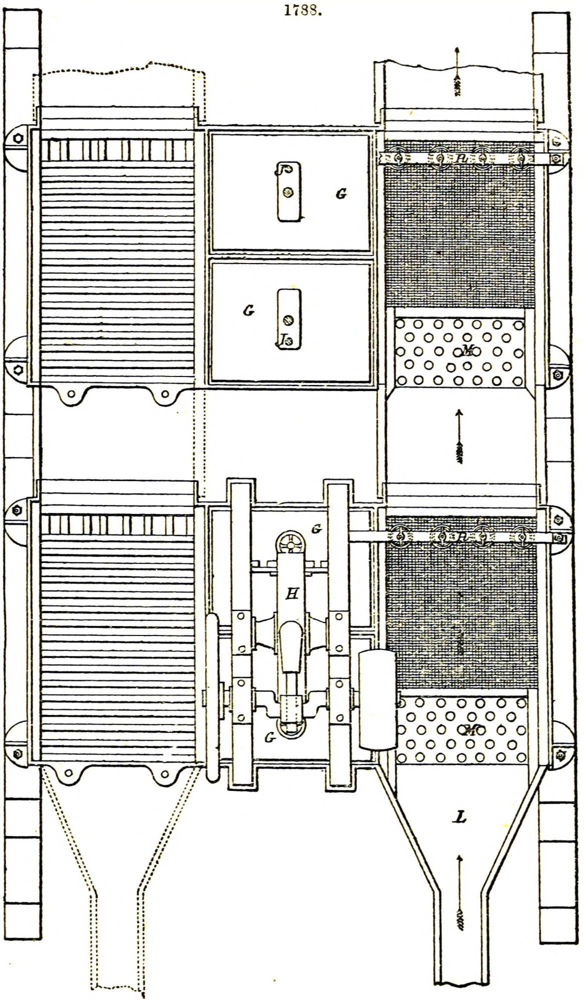
An improved form, Collom's jigger, Figs. 1787, 1788, is in use for washing stream tin, and appears to be equally applicable to copper dressing; it is in extensive use for dressing lead and other minerals in Wales and in America; like all other jigging machines, it is only available for dressing stuff from which the slimes have been previously extracted by a proper separator. The jigging action is produced by two pistons G G, fitting loosely in square trunks, and having a very short vertical stroke of from $\frac{1}{2}$ in. to 1 in.; coarse ore requires the longest stroke. Each piston is struck down alternately by the blows of a rocker H, and raised again by a spiral spring upon the piston rod, which brings it up against an adjustable stop J; the rocker H is actuated by a crank making about 120 revolutions a minute. The space under each piston is in communication with one of a pair of hutches K K as in the transverse section, Fig. 1787; and on the top of each hutch is fixed a fine sieve of brass wire, upon which is spread a bedding of coarse ore in a layer about $\frac{3}{4}$ in. thick. The stuff to be jigged is supplied through a launder L with a continuous gentle current of water, and is delivered upon one end of the sieve through a distributing grate M; the sieve is set with a slight fall of about 1 in 140 towards the opposite end. The hutches are kept constantly filled with a supply of clear water, under a pressure of 2 ft. head or upwards, by the pipe P, and there is a constant overflow of water from the lower end of the sieves, carrying away the lighter stuff that is separated by the jigging process. The pulsating action of the pistons gives a jerking motion to the water under the sieves, driving it up through them, and producing

1787.



the same effect in separating the stuff upon the sieve as in the ordinary jigging machines, where the sieve itself is jerked up and down in the water. The lighter particles are thus lifted and gradually carried off in the stream of water flowing over the sieve, leaving the heavier rich stuff to settle down gradually through the sieve into the hutch below, from which it either passes off continuously through a regulating hole at bottom, or is discharged at intervals if the supply of water is scarce. In order to prevent accumulation upon the sieves of any stuff which may be too light to pass through the bedding on the sieves, yet too heavy to be carried over the lips of the hutches by the overflowing stream of water, ragging gear R is in some cases provided, consisting of a row of holes closed by taper plugs fitting into conical seatings; the height of the plugs is adjusted by thumb screws so as to regulate the area of the openings according to the quantity of stuff to be got rid of, which never amounts to much; this falls through into a separate compartment S of the hutches, and passes out through a hole at bottom. A second complete jigging machine is fixed immediately in front of the first and at a few inches lower lever, by which the overflow from the first is received and worked over a second time in a similar manner. In this jigger a very complete separation of the different qualities of ore is effected by an entirely self-acting process, and with a very small proportion of loss in the waste. In the use of the jigger for separating the tin from the gravel and sand in which it is found, almost the whole of the tin ore contained in the sand, becomes deposited in the upper pair of hutches, the contents of which are then worked over in the propeller knife buddle; from the sand deposited in the lower pair of hutches some inferior ore which requires stamping is extracted in an ordinary strip. There is a large amount of slime with the tin sand raised at these works, but it is separated from the sand before the stuff passes on to the jiggers, by a slime separator attached to each jigger. The sand that passes off through the ragging gear requires to be stamped to a finer size, and is then washed over again.

1788.



In the cushioned crusher of T. A. Blake, Fig. 1789, made by the Blake Crusher Co., Connecticut, a three-sided framework of cast iron, with broad flanged base, holding the movable jaw in suspension, forms the front part of the machine, between the upright convergent jaws of which the stone is crushed.

The jaw shaft is held in place by wrought iron or steel clamps C, which serve to take part of the strain due to crushing in the upper part of the jaw space, and also act as walls. In the lower part of the frame, and on each side of it, are holes in the casting to receive the main tension rods which connect the front and rear parts of the machine. The rear part B is called the main toggle block, and is also provided with holes for the tension rods R, corresponding to those in the front casting.

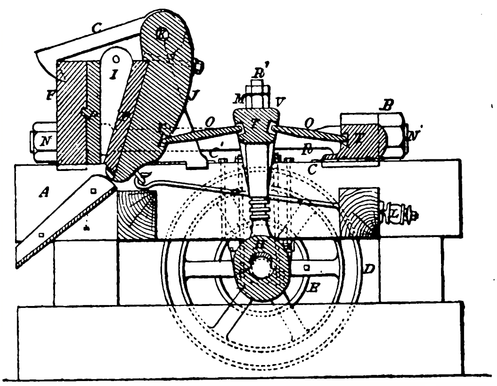
These two parts of the machine are connected by the main steel tension rods R, each provided with screw thread and nuts, by which their lengths and the jaw opening are readily adjusted to crush coarse or fine, as may be desired.

The front and rear castings are supported on parallel timbers, to the under side of which are bolted the boxes carrying the main eccentric shaft, provided with fly-wheels and pulley. The timbers are thus made component parts of the machine, and take the transverse strain which comes upon the pitman connecting the main shaft and the toggle joint, placed in the rear of the movable jaw, and between it and the main toggle block.

Between the broad-flanged bases of the front and rear castings, and the timbers on which they rest, are placed flat rubber cushions $\frac{1}{4}$ to $\frac{3}{8}$ of an inch thick. Every revolution of the shaft brings the toggles more nearly into line, and throws the swing jaw forward; it is withdrawn by the rod provided with rubber spring L. In this way, a short reciprocating or vibratory movement is communicated to the movable jaw.

It is evident that in this construction of the Blake stone crusher, while the principle of crushing between upright convergent jaws is the same as in the old machine, there are many and great advantages over the old forms. It is sectional. The weight of the heaviest piece in crusher, size 15 × 9 in., is about 2400 lb. instead of nearly 8000. The rigidity inseparable from machines with cast-iron frames, and which is the cause of frequent breakages, is completely overcome, and the longitudinal as well as transverse strains, are brought upon materials which are strong and elastic as compared with cast iron. The rubber cushions, while offering sufficiently great resistance to compression in case of the breakage of stone, or in doing the normal work of the machine, will, in case of the accidental intrusion of steel hammers or anything of that kind, be compressed, and so permit the partial revolution of the fly-wheel before coming to a full stop, thus relieving the machine of those nearly infinite strains to which those of the old form were subjected, and which resulted in breakage of important parts. The toggles are long, and of equal length, and may be worn indefinitely as compared with those in the old machine. The construction of the pitman is such as to admit of change of inclination of the toggles, and, consequently, of adjustment of the length of stroke of the movable jaw. The jaw opening can be varied between any working limits, by means of the nuts on the tension rods, and the machine be set to crush coarse or fine, as may be desired. The crusher, it is stated, can be run at a higher rate of speed, with safety, than either of the old forms of crusher with cast-iron frames, and will, consequently, do a greater amount of work. The manufacturers state that while this machine is very much lighter than the old forms, it has at least double their strength.

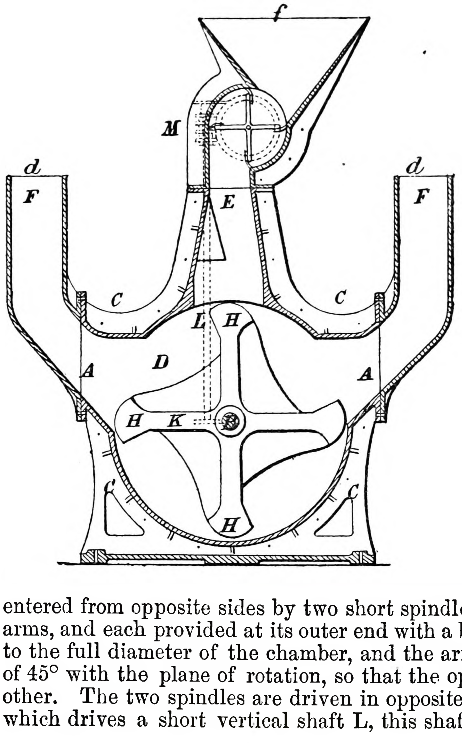
1789.



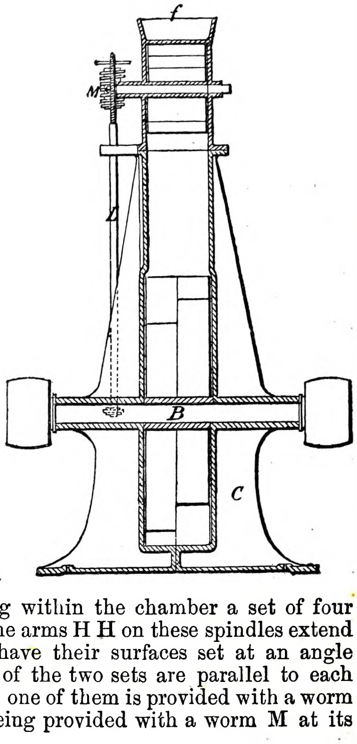
Blake's cushioned crusher has been repeatedly subjected to the test of a steel hammer being thrown between its jaws, when going at as high a rate of speed as 300 revolutions a minute, without injury to or breakage of the machine.

The pulverizing machine made by Jordan and Son, London, Figs. 1790 and 1791, which is very simple, is formed of two castings which, when bolted together by their flanges, form a couple of circular chambers as shown. The lower and larger chamber D is the crushing chamber, and it is entered from opposite sides by two short spindles, each carrying within the chamber a set of four arms, and each provided at its outer end with a belt pulley. The arms H H on these spindles extend to the full diameter of the chamber, and the arms of each set have their surfaces set at an angle of 45° with the plane of rotation, so that the opposed surfaces of the two sets are parallel to each other. The two spindles are driven in opposite directions, and one of them is provided with a worm which drives a short vertical shaft L, this shaft in its turn being provided with a worm M at its

1790



1791.

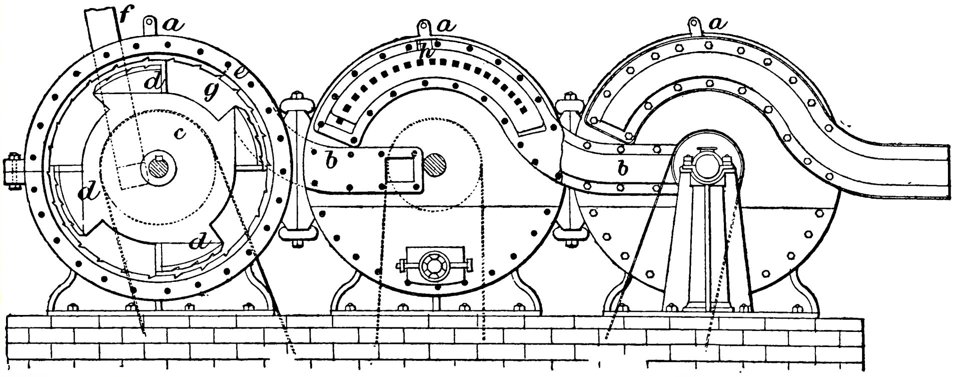


upper end, by means of which it drives a spindle traversing the upper and smaller chamber already referred to. In this chamber works an automatic feeder by which the supply of materials to the crushing chamber is secured.

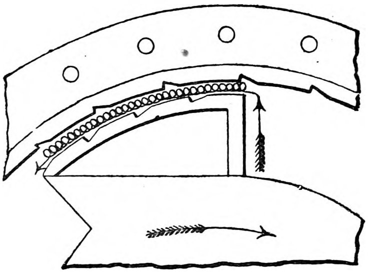
The materials to be crushed enter the crushing chamber by the passage E, and are delivered through the channels F F, by means of the current of air which traverses the crushing chamber. This current of air is produced by the rotation of the arms H H, the air entering through openings in the sides near the centre of the chamber. By opening or closing these apertures the strength of the current can be controlled, and the degree of fineness to which the materials are ground before delivery thus regulated. The discharge current is sufficiently strong to carry up the crushed materials to a height of from 10 ft. to 20 ft. according to their fineness, the height of the delivery column also regulating the fineness of the particles delivered, and different sizes being delivered at different levels if required.

Pulverization of ores by attrition of the particles upon themselves, has been successfully carried out in the machine devised by Van Buren Ryerson, of New York, Figs. 1792, 1793. The principle involved in the reduction of ores by this machine is, that the ore particles are caused, by mechanical means inducing a peculiar application of compressed air, to rotate violently, each upon its own axis, at the same time having a path of revolution about a common centre; and at a certain stage of their reduction into granulations, the size of which is regulated by the opening or closing of the discharge ports, thereby varying the pressure of air within the case; the powdered material is discharged at right angles to the plane of velocity. This is accomplished with little wear to the machine, as the particles touch no part of the mechanism during their pulverization. This rotary movement of the ore particles is induced by a succession of eddies or reactionary air currents, in opposition to the direction in which the particles at a high velocity are moving, thereby causing the particles to be rubbed upon each other, and reducing themselves to an impalpable powder.

1792.



1793.



Reference to Fig. 1792 will show that the machine comprises three circular metallic cases *a*, each about 3 ft. 9 in. in diameter, discharging into one another through the pipes *b* at either side of each case.

Within each case is a revolving disc of gun-metal *c*, having at its outer periphery the four beaters *d*, the upper and front faces of which are of the full width of the space between the inner sides of the case, the disc *c* being of a thickness to secure strength and solidity. The outer face of each beater *d* is ratchet dressed, while the radial face is smooth. These dressings extend across the full width of the beaters, and are of uniform depth. The inner periphery of the case *a* is provided with a stationary ring of steel *e*, which is dressed in the same manner as the outer faces of the beaters. This construction will more readily appear in Fig. 1793. The distance, therefore, between the outer faces of the beaters and the inner periphery of the case, varies alternately from three-quarters of an inch to an inch and a half, from the apex to the base of each two notches of the dressings, when directly opposite each other.

When the disc *c* is revolved at a high rate of speed, causing a rotation of the central body of air in the case, it produces a reactionary effect upon the belt of air, lying between the path of revolution of the upper faces of the beaters and the dressed surface of the inner periphery of the case. The use of the ratchet dressing on the inner periphery will now be understood. It is not intended for grinding; but its purpose is to present a succession of abrupt surfaces, radial to the circle in which the belt of air revolves, which serve, by the impingement of this belt of air upon them, to break it up into whirlpools and eddies. These eddies of air, while each revolves upon its own axis, have also a path of revolution about a fixed centre. This peculiar action of the compressed air is shown clearly in Fig. 1793, where the scrolled line represents the eddying character and direction of the current.

The ore to be reduced to powder after having first been crushed fine in a Blake ore crusher, is introduced through the feed-pipe *f* at the centre, at both sides of the first case of the series. At the instant the crushed ore enters the machine, it flies outward in radial lines toward the periphery of the case, and is there caught up by the revolving belt of air-eddies, and each particle of ore is then rapidly reduced to powder by the violent attrition of the particles upon each other. The pulverized ore is discharged at right angles to the plane of velocity through the port-holes *g*, and forward into the next machine, where the particles are still further reduced.

The size of the granulations will depend upon the length of time that the ore-particles are retained within the case. The port-holes *g* are covered with the slide *h*, in which are port-holes of a like size and number, so that when this slide is moved backward or forward, the discharge of air is lessened or increased, and it simply rests with the discretion of the man in charge of the machine to regulate the size of the granulations of the powdered material. This feature of the machine is absolutely necessary, as it may often occur that the ore to be pulverized will be of varying degrees of hardness.

The second revolving disc moves with a greater velocity than the first, and the third with a greater velocity than the second. Thus there is the combined pressure from the first case, and suction from the one into which the material is discharged. The powdered material comes from the machine perfectly cool.

The various metallurgical processes for the working of silver and gold ores depend upon having some other metal, generally mercury, lead, or copper, as an intermediate product, in which the precious metals can be concentrated.

Wet processes, such as Van Patera's leaching process for silver and gold chlorination in California, where it is only applicable to gold ores, are used. It is necessary that the ores so treated should be very finely crushed, and they generally come as an accessory product from the amalgamation process. To be carried out cheaply the work should be done on a very large scale. Although successful in a metallurgical way, the chlorination process is often not successful financially, owing to the impossibility of getting a sufficient supply of ore at all times. Up to this time (1879) it has only been applied to the concentrates from gold mills. It cannot generally be used for the concentrates of silver mills, because all the silver contained in them would be lost.

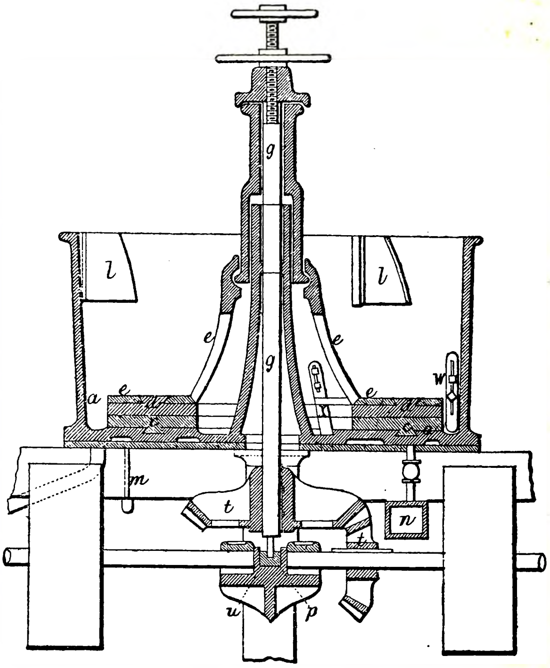
The processes in use in the United States for the extraction of silver are; pan amalgamation, lead fusion, and fusion with copper ores. The first is applicable to ores containing very few base metals, the second to ores occurring in galena, where the galena is in excess, and can be had in quantities; the third is applicable to ores carrying copper, which usually contain considerable gold at the same time.

The general arrangement of the mills is the same, exception being made of the presence or absence of roasting. When roasting is done, the ore is crushed dry; when it is not, it is crushed wet.

About 25 to 30 per cent. of the Comstock ores is gold, the rest is silver; but in the bullion produced the proportion is somewhat higher, as the gold is more completely saved than the silver. As a general thing, the richest ores are treated by dry crushing and roasting, and the poorer ores are crushed wet and directly treated by amalgamation, which is the Washoe process.

The ore is delivered to rock breakers placed at the highest level of the mill. Below the rock breakers, between them and the batteries, the drying floor in dry crushing is placed. This floor is made of cast-iron plates, 36 in. by 42 in., flanged on the sides, so that the plates may overlap and still give an even floor. A flue from the roasting furnace runs backwards and forwards under this floor, the partition walls of which serve as supports for the plates. This floor is placed directly behind the stamps, and the ore is spread over it until dry, when it is charged by hand or automatically into the stamps, which are on the same level. Below the discharge level of the stamp, the roasting apparatus, if the ore is to be roasted, is placed in such a position that the ore from the stamps can be discharged into them, or be carried by a screw conveyer or an endless chain to an elevator which discharges into hoppers containing a charge for the furnace, when the ore is to be roasted or chloridized, or both. The supply of ore is cut off from the furnace automatically, when the hoppers are full. The speed of the elevator feeding the pulp into the hoppers is regulated by two sets of cone pulleys, and may be made to vary from 40 to 300 revolutions a minute. In front of the furnace there is a brick or iron cooling floor, where the ore remains until it is cool enough to be charged into the pans. On a still lower level are the pans and catch-pits, if the mill is wet crushing, and lower still the settlers. The power for the mill is generally steam, sometimes water, and sometimes both together. It is communicated to the various parts of the mill by shafts above and underneath the floors. Each kind of machinery has its own independent line of shafting. The power is always transmitted by belting. The power required to drive the pan is from three to six

1794.



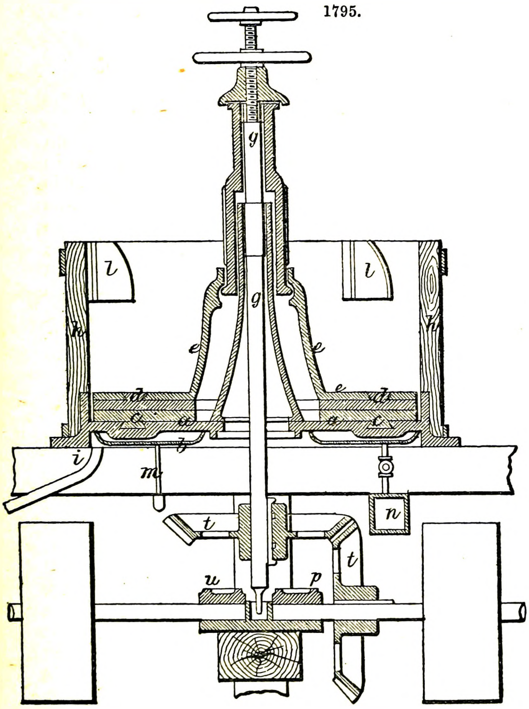
horse-power, according to its capacity. The power required to crush and amalgamate one ton of ore will vary from three to five horse-power.

The process of amalgamation is the same, the barrel process having almost entirely disappeared. The process of crushing is generally the same, and consists in the use of revolving stamps, the crushing being either dry or wet according to circumstances. Silver ores, which can be amalgamated directly, are generally crushed dry. The general outline of crushing is, first, to reduce the rock in a crusher to a certain size. It is then fed under stamps, and the slimes afterwards conveyed to the pans.

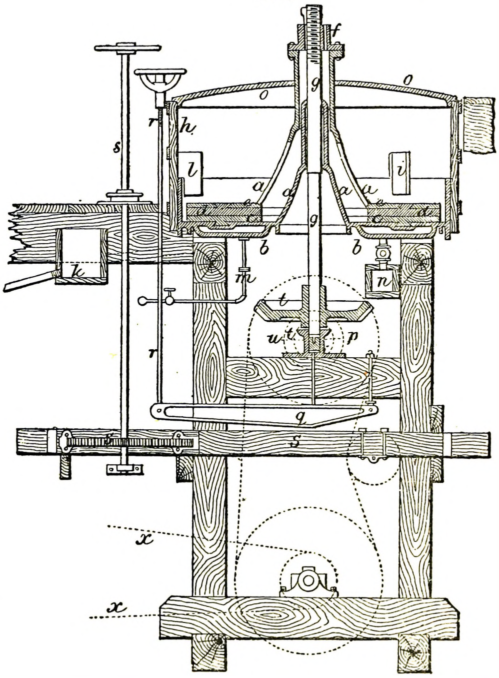
The Horn pan, Fig. 1794, has iron sides *a*, and a flat bottom, and also has a steam bottom, which is composed of a flat plate, upon which the pan is bolted. The space for the steam from the pipes *m n* is made by the two hollows formed by the projections necessary for the sockets of the die *c*. The shoes and dies are fastened in the same way as in the Wheeler pan. The muller *e* is not, however, fastened to the driver, but is caught in grooves, so that it moves only when the driver is turned in one direction, in the other it is loose. The height of the shoes and dies is regulated by two handwheels at the top of the shaft *g*. On the circumference of the inside of the pan, there is a groove into which a scraper W is introduced, as in Fig. 1794. A scraper X′ is also attached to the inside of the muller, fitting into a similar groove there. The shape of the wings is different from that of the Wheeler pan. A yoke *u p*, which carries the bearings for the vertical and horizontal shafts and the gear wheel *t*, is attached to the bottom of the pan. This yoke and the scrapers are the peculiarities of this arrangement.

The Patton pan, Fig. 1795, is a combination of the Wheeler and Horn pans. The steam bottom *b* is fastened in the same way, but is not exactly like that of the Horn pan. The sides *h* are of wood supported by a flange, which is nearly as high as the muller *e*, in order to prevent the loss of mercury, and is a much better disposition than that adopted in the Wheeler pan. It has the same wings as in the Horn pan, but no scrapers. The bearings *u p* for the gear wheels *t t* and horizontal shaft are set on a beam underneath.

1795.



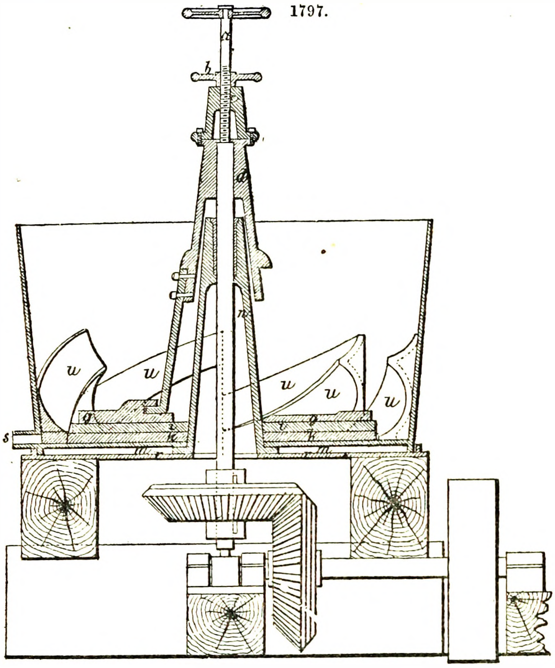
1796.



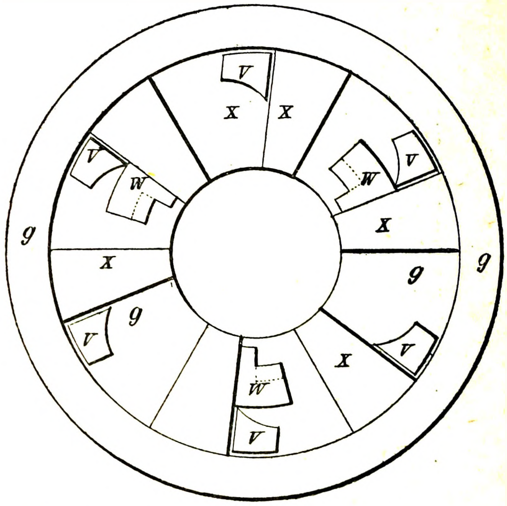
The Combination pan, Fig. 1796, is a combination of the Wheeler and Patton pans, with a number of improvements on both. Its capacity is 15 tons in 24 hours. The cast-iron ring *a* on the inside is carried much higher, and is made so that it can be removed when necessary. The sides *h* of the pan are of wood. From the top of the iron rim, about 6 in. of the sides is lined with $\frac{1}{8}$-in. copper plates, and the wings *i l* have also copper plates, 16 in. wide at the bottom, and 10 in. at the top, bolted to them. This is done to help the amalgamation, which is always finer on the copper than on the iron. Some of the chief advantages of this pan are that the muller *e* is loose from the muller stem *g*, and that both the muller and the shoes *d* fit into slots. The revolution of the muller keeps them in place, but with a bar they can be easily forced out when necessary. The muller is fixed in the stem by means of a key *f* in the screw thread; by taking out the key and turning the muller on the stem, it may be raised and kept at any height for any length of time, and as easily lowered. The three wings *i l* are attached to pieces of iron, which are dovetailed to fit into slots in the side of the pan. A handwheel *r* and lever *q*, raises or lowers the block *p*, and so regulates the distance between the shoes and dies.

Stevenson's pan, Figs. 1797, 1798, does not possess some of the mechanical advantages of the Combination pan, and has less grinding surface, though the distribution of the pulp throughout the pan is more perfect than any other, on account of the four double curved mould boards *u*, which are introduced to throw the pulp to the outside and upper part of the pan, from which it falls again under the muller, and so ensures a maximum amount of grinding. As the mullers are nearer the centre of the pan, less power is required to do the grinding than in other pans of the same capacity. The moulds raise the pulp regularly without violence, and admit of a larger charge in the pan. It has a steam bottom like the other pans, and the suspension is the same as in the Horn and Patton pans. The muller *g* is attached to the driver *d*, which is keyed upon the shaft by four legs *e*, so that the space between them and the cone is entirely free. It has six shoes *i*, which weigh 100 lb. each, and eight dies *k*, which weigh 85 lb. each. The arrangements for driving the pan are the same as in the others; it has a capacity of 3500 lb. of pulp. Its total weight is 6500 lb.

1797.



1798.



The foregoing particulars are taken from an excellent series of articles upon Amalgamation by Dr. T. Egleston which appeared in the pages of 'Engineering' in 1879. The subject has also been already treated at length in the articles Amalgamation Pan, Battery, Ores, and Silver, in this Dictionary.

PIERS.

The most ordinary construction for modern piers consists of circular hollow cast-iron screw piles, supporting cast-iron hollow cylindrical columns, braced diagonally or otherwise by wrought-iron bracing, in compression or in tension; these, in turn, sustaining a timber superstructure. There are, however, various other descriptions which are frequently employed. It is not unusual to meet with a combination of various different materials in the same work. For instance, a pier, the body of which is of the ordinary cast-iron construction of screw piles and columns, may carry a timber head; or a timber body may be supplied, either at first, or, as is frequently the case, at a subsequent period, with an iron head; and this, again, may be either cast or wrought.

In Figs. 1799 to 1801 the cast-iron construction ordinarily applied is illustrated, the example given being the pier at Westward Ho! The deck of the pier is here 16 ft. in width, and is composed of open 9-in. planking, 2½ in. thick, running longitudinally, and spiked down to transverse joists, 11 in. by 2½ in., placed 5 ft. apart. These joists are supported upon two parallel 12-in. by 12-in. balks, extending throughout the body of the pier, at a distance apart of 13 ft. from centre to centre. In lieu of a railing on either side, seat standards are supplied, fitted with timber seats, and forming sitting accommodation throughout the entire length of the work. They are of cast iron, placed 5 ft. apart, one upon each joist at each end, and the back of the standard is filled in with four rails, the upper one being formed of 2-in. wrought-iron tubing, and the lower ones of ordinary 1-in. round bars.

The body of the pier is subdivided lengthwise into bays of 30 ft., the longitudinal balks supporting the deck, resting at either end upon timber corbels, 10 ft. in length and of similar scantling to the former. Beneath the centre of these corbels the load is taken by a cast-iron spreading bracket, the lower flange of which is firmly bolted to the upper end of the cast-iron column. These columns terminate in cast-iron screw piles entering the ground, each pair of columns inclining inwards at the top, and being held in place in an upright position by a horizontal 4-in. T iron extending acros the structures above, and another similarly below, the whole pier being also diagonally braced by adjustable 1½-in. wrought-iron rods, bearing at either extremity a right or left-handed screw for adjustment, and bolted together, in addition, at the point of crossing. The longitudinal 30-ft. balks are doubly trussed by 1½-in. wrought bars, one on each side; and where the fall of the foreshore necessitates a stronger form for the supports in the deeper water, nests of four piles are substituted for pairs of columns, these being braced quadruply, and carried out in a second set below the first, if required.

Dixon's cast-iron piles are shown at Fig. 1803, and are designed for the purpose of driving in foreshores, where the ordinary screw or driven timber piles would be otherwise employed. They are usually of about 8 in. internal diameter, and 1 in. thickness of metal, cast in the form of a hollow cylinder, with four projecting ribs running the entire length of the piles, the external diameter over the flanges being 14 in. The principal objection to driving cast-iron piles is the liability of the material to fracture under concussion, and this Dixon avoids by the employment of a wooden dolly above the head of the pile. This is turned to fit the interior, and shouldered so as to rest upon the socket, a ring of indiarubber, or some other yielding compressible substance, being inserted between this shoulder and the iron, to deaden the concussion. By this means it is found that these piles may be safely and successfully driven to a great depth.

1799.

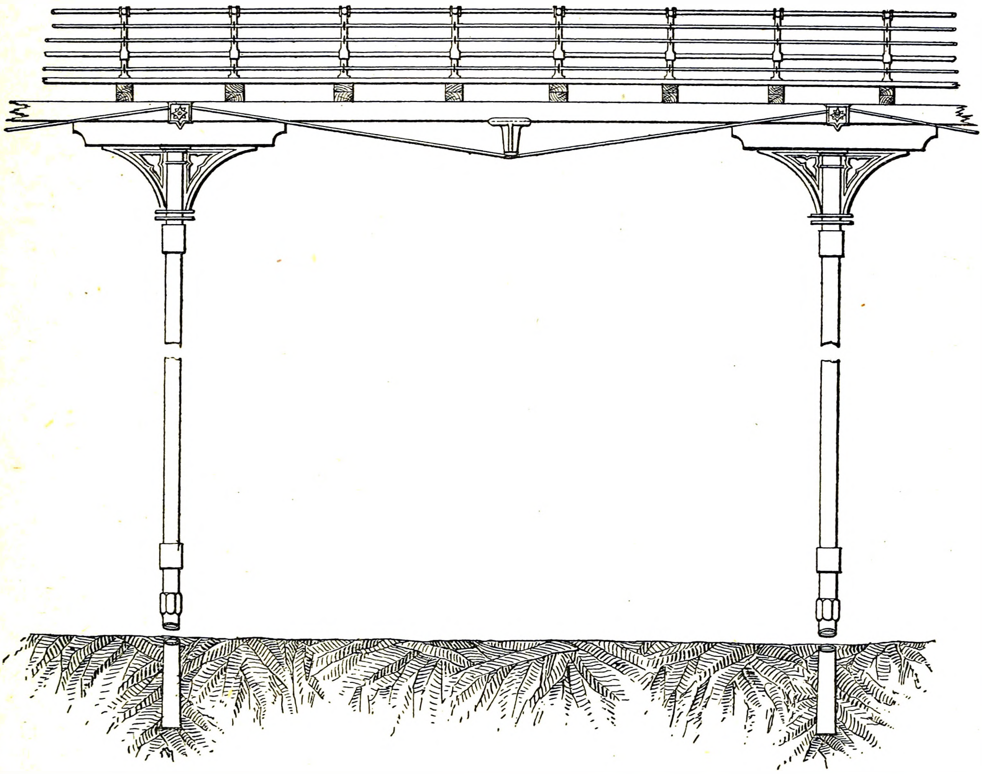


Fig. 1804 is a section of a circular column such as is commonly used in combination with a screw pile. It is introduced here for the sake of comparison; its diameter is externally 9 in., with a thickness of ¾ in., these dimensions being varied according to circumstances.

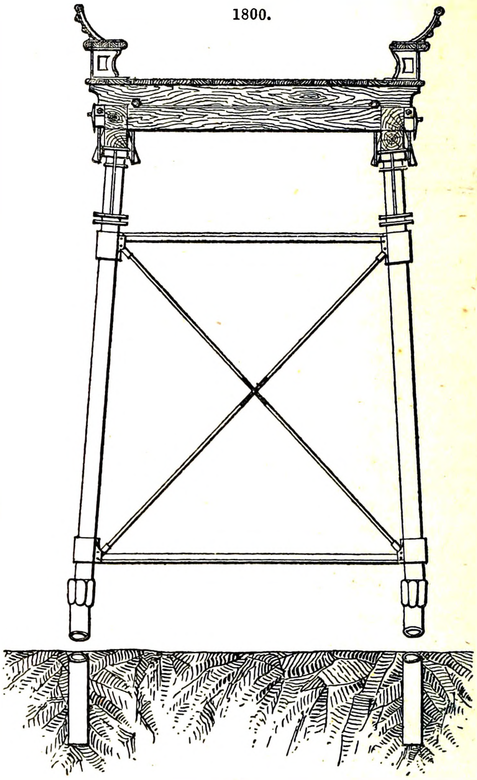
Dowson's wrought-iron columns are formed from plates rolled to the form Fig. 1802, and riveted together in sets of four, in order to obtain the required circular form. Singly, these rolled plates are frequently employed for the covering of bridges and other similar works, in cases where it may be an especial object to economize headway, being laid side by side as at Fig. 1805. For combination it will be seen that these plates form a good and rigid piece of work. Dowson's piles are usually of an internal diameter of 8½ in. The thickness of the plates from which they are rolled is ⅜ in. or thereabouts, and the thickness of each plate, laid flat, is from 1½ to 1¾ in.

Fig. 1806 is a section of one of the columns which are frequently constructed from a pair of Barlow rails. These are riveted together, back to back, in convenient lengths, forming a column of 14 in. diameter. These rails are now seldom employed for permanent way, and consequently they may readily be procured at a moderate cost for pier work.

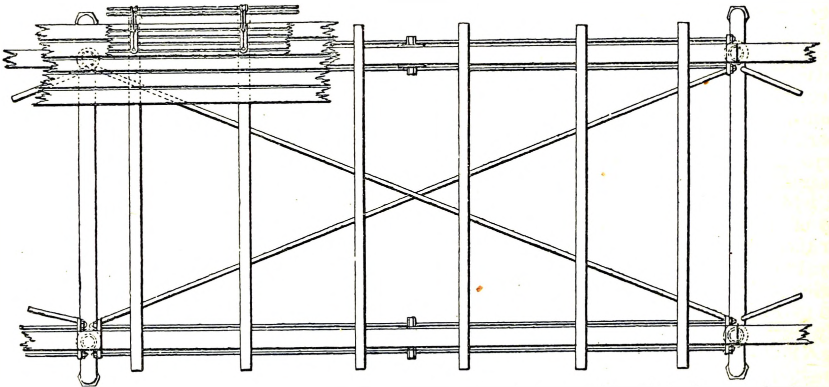
Fig. 1808 shows a section of a wrought-iron column, invented by J. W. Wilson, employed for the construction of the pier at Westward Ho! These columns were formed of two side plates of wrought iron 1 in. thick, connected by two intervening 7-in. channel irons, one having the channel facing outwards, the other facing inwards. The plates and channels are connected by plain and countersunk rivets; by this means a rigid 9-in. upright was formed. The external channel iron, in this case, is well adapted for the reception of the requisite rubbing timbers necessary at the head of a pier. The ends of these columns are bent over outwards on all four sides, and finished so as to form a circular flange, which may be readily connected with corresponding flanges on the piles below or the structure above.

The piles, Fig. 1807, are those which were employed in connection with the columns just described. They were of cast iron and hollow in section, of an external diameter of 9 in. immediately below the upper flange, and increased gradually in diameter to 11½ in. at the lower extremity; the total length was variable, according to the section of the foreshore, and the distance of the pile in the rock was 3 ft. 6 in. The metal of the pile in the upper part was 1½ in. in thickness, and this gradually increased until, at a point 6 in. below the surface of the rock in which it was sunk, the thickness of metal was 4 in. on either side. From this point the contracted opening in the centre of the pile gradually expanded, the metal being reduced to 1 in. in thickness at the lower extremity. By this means a pile was obtained of sufficient rigidity for the wrought-iron superstructure, and one which was free from the objections to wrought-iron piles. The holes sunk in the rock for the reception of these piles were of 13 in. diameter, and they were sunk parallel downwards, the surrounding space being filled with cement, giving a perfectly solid foundation to the superstructure. The piles were also filled up to the ground line internally with cement concrete. The body piles of this pier were of similar construction to the head piles, the flange at the top being replaced by an ordinary octagonal socket, for the reception of a cast-iron column. A plan, due to Brunlees, is frequently adopted for the purpose of obviating the screwing of piles, in foreshores in which sand is the principal ingredient. The piles in question are of cast iron and of ordinary diameter, having the base extended considerably to afford sufficient support for the superstructure, and finishing at the lower extremity in a greatly contracted opening of from 2 in. to 3 in. diameter. This enlarged base bears toothed edges, in order to pass freely any interposing layer of hardened mud, or clay, or other obstacle. A tube of iron passes down the centre of the hollow pile or column, of such a diameter as to fit the small opening below in the disc base, beyond which it extends for a short distance. The upper end of this tube is placed in connection with a pliable hose, by which means communication is established with some convenient pumping power, and the whole apparatus is supported as found most convenient, according to circumstances. On pumping being commenced with the pile in position, the sand is disturbed or blown up on all sides by the downward force of the constant stream supplied, and the pile rapidly descends, and a constant reciprocation supplied at the same time by external contrivance, prevents clogging and aids the descent.

1800.



1801.

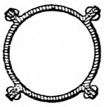


The pumping is suspended as soon as the necessary depth is considered to be reached, and the tube being extracted from the interior, the disturbed sand immediately surrounding the pile gradually settles down and becomes quite solid. Piles may be sunk by this means to a depth of 17 ft. or 18 ft. in from twenty to thirty minutes.

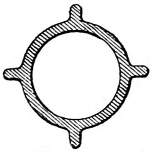
This process may be equally well carried on upon the foreshore itself, or from a raft; and is claimed as being the only one by which such depths are reached with piles containing such a minimum quantity of metal.

Localities are frequently met with where the nature of the situation, the excessive rise and fall of the tide, the exposed position of the structure, or some other reasons necessitate the elevation of the deck to a greater height than is ordinarily the case. In such instances it is usual to employ wrought-iron work to a larger extent, not only in the superstructure, but in the supports to the work themselves. As an instance of this may be mentioned the pier erected at Clevedon, in Somerset.

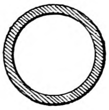
1802.



1803.

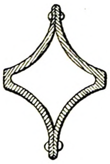


1804.

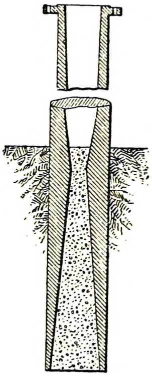


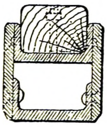
1805.

1806.



1807.

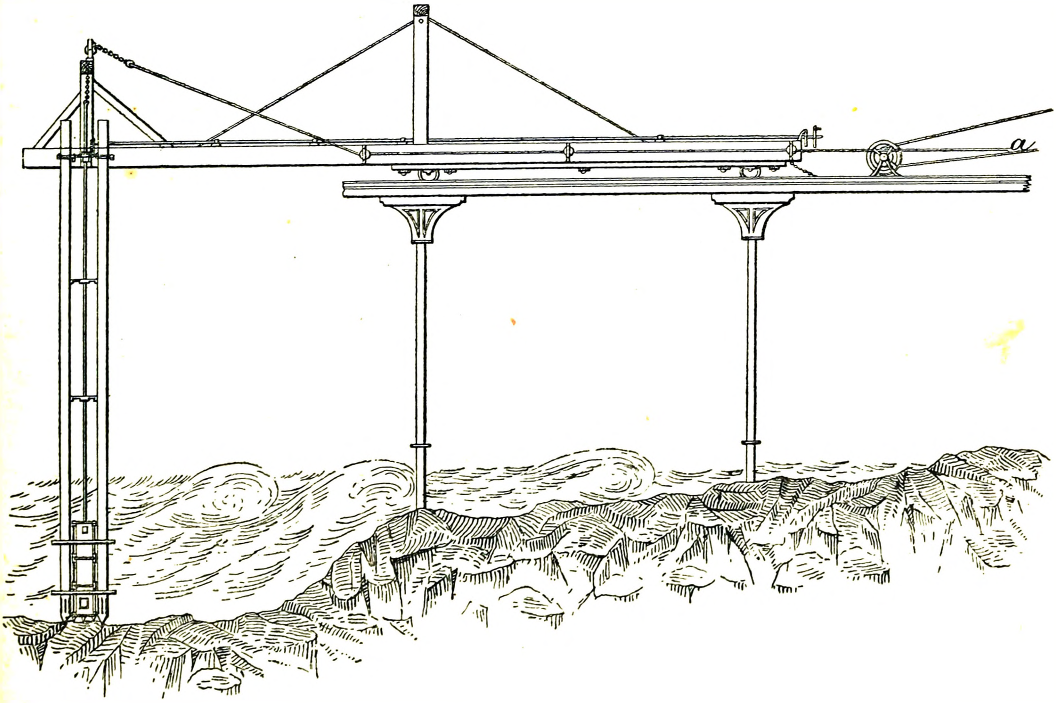




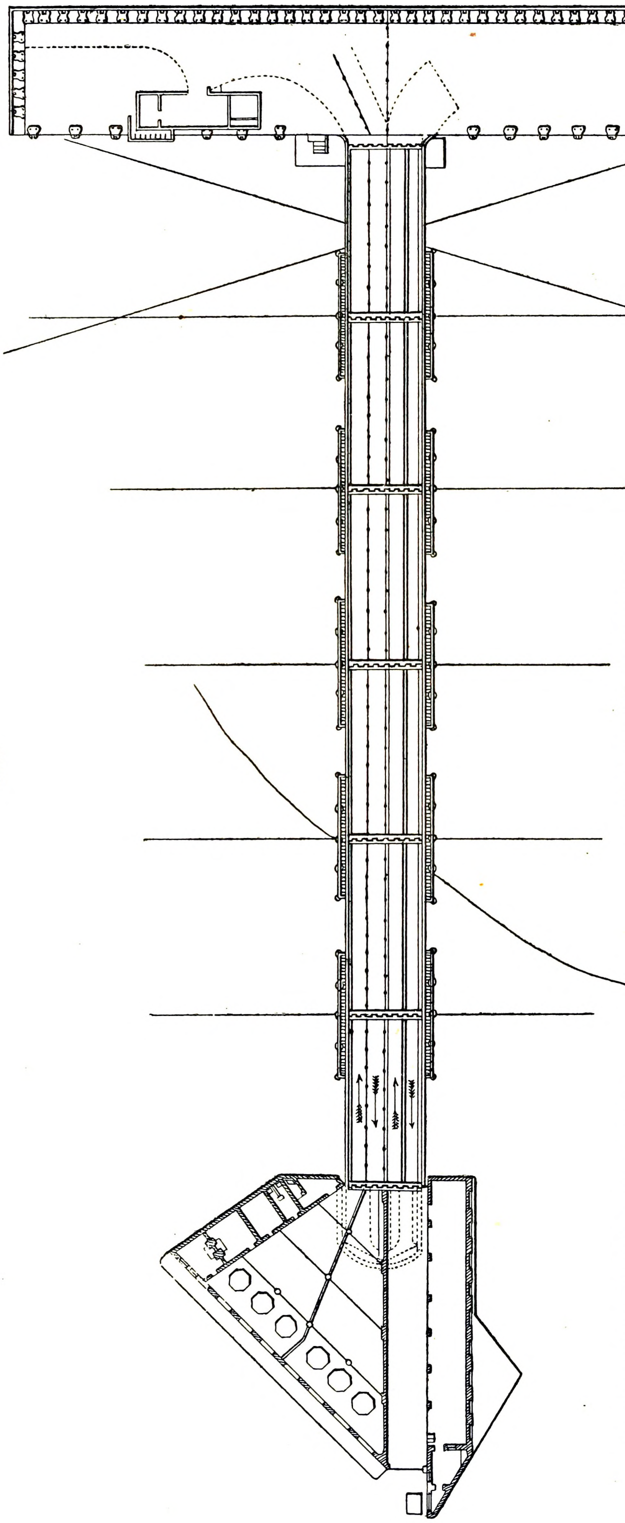
1808.

There is a rise and fall of tide here of nearly 46 ft., and wrought iron may be called the exclusive material of which the work is constructed, there being considerably less than 10 tons of cast iron employed, while there are said to be upwards of 350 tons of wrought work in the structure in all. The main part of this structure is formed by two wrought girders formed of plate work, and extending in two parallel lines continuously throughout the work; and the pier is divided into eight bays of 100 ft. each, being supplied with a T head 42 ft. broad and 50 ft. long. The depth of these girders is 3 ft. 6 in. The columns employed were those mentioned previously as being formed from combined pairs of Barlow rails riveted together, and extended above the ground to a height of no less than 65 ft. They were connected with the shore, which consists of hard limestone covered with mud in a moist state, interspersed with loose rocky blocks, by means of a solid wrought-iron bar extending in a downward direction as far as the solid rock, a distance of sometimes 14 ft. or 15 ft. The bar had at its extremity a cast-iron screw of upwards of 2 ft. diameter. Thus, in this work the total length over all, of pile and column, reached in some instances as much as 80 ft. The stability of the structure is further increased by the rails forming the columns being convergent, and being bent over at the top in either direction, by which means is formed an arch of great rigidity. The total length of Cleveland pier over all is 842 ft., and the breadth of the body 20 ft. At low-water spring tides the depth of water at the head is 6 ft. The Westward Ho! pier to which reference has already been made was constructed by J. Wilson, and runs out seawards from the shore in Bideford Bay, extending in a northerly direction. The foreshore below the cliff, which is

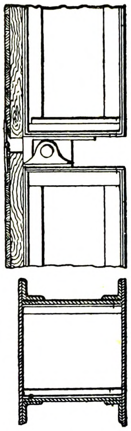
1809.



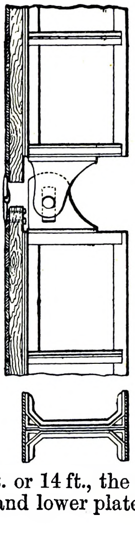
entirely composed of rocky shale, dipping at an angle of about 45°, is covered at high tide with a depth of from 6 ft. to 33 ft. of water. The shore falls from below the cliff at an incline of about 1 in 35 for a distance of about 360 ft., when there occurs a sudden fall of 12 ft. or 14 ft., the shore then running out seawards at a gradual slope of 6 in. in 100 ft. These upper and lower plateaux are of



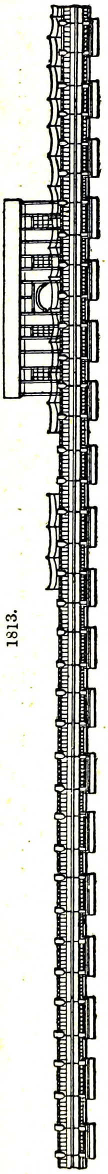
1810.

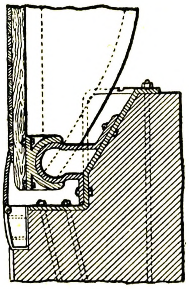


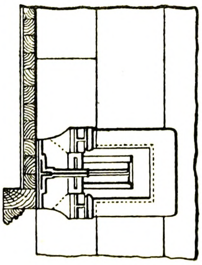
1812.

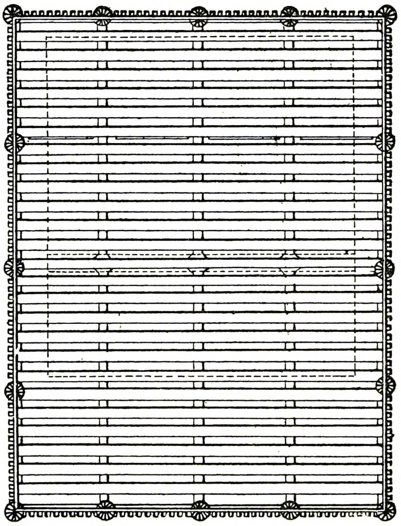


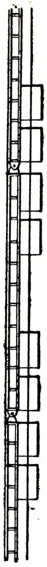
1811.

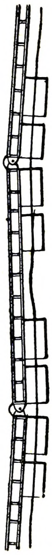

1813.

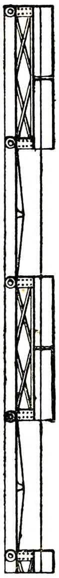

1814.

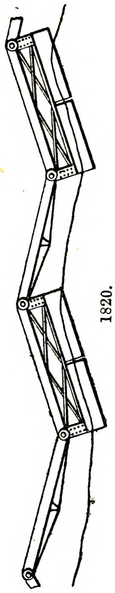

1815.

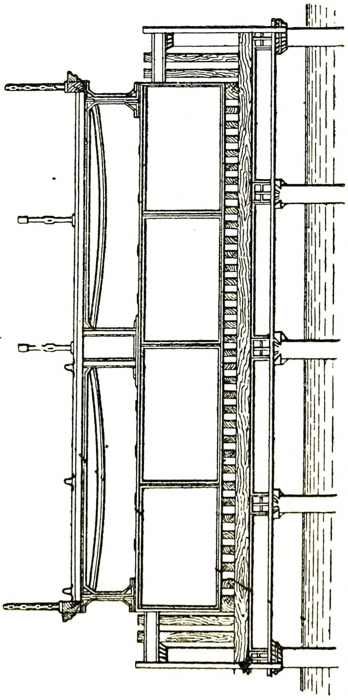

1816.

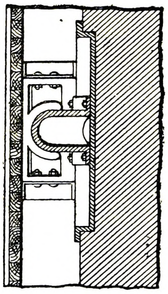

1817.

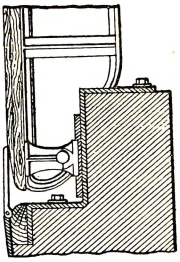

1818.


1819.


1820.


1821.


1822.


1823.

moist irregular surface, the upper one especially being intersected by deep gullies running in various directions. The shale is much hardened on the upper or exposed surface. These two plateaux are covered with large oblong flint and other boulders, varying in size from 6 in. to 2 ft. to 8 ft. diameter.

The pier is erected upon cast-iron columns, with the exception of the head, where the greater depth of water necessitated the use of the wrought-iron columns, Fig. 1808. In all cases both descriptions of columns are placed upon cast-iron cylindrical piles, Fig. 1807. The holes required to receive these were sunk in the rock by jumping, where practicable, but otherwise, the plan adopted for sinking the piles in the foreshore under water, is that shown by Fig. 1809. The piles were of lengths varying from 12 ft. to 15 ft., as required by the formation of the ground and the arrangement of the superstructure, and they were of 11 in. external diameter. The holes in the rock to receive them were 12 in. diameter. The depth of water over the holes varied from 6 ft. at low water to upwards of 30 ft. at high water. An outrigger was constructed of timber to project 35 ft. beyond the present end of the pier; this outrigger being supported at the extreme end by spars shod with iron, resting upon the rock in which the holes had to be worked. An iron cylinder 8 ft. long and 14 in. internal diameter, made in halves and jointed, the joint being parallel to the length, was lowered on each side of the outrigger, and kept in an upright position by being firmly secured to the spars. The position of the outrigger, spars, and cylinders was arranged so that the cylinders stood on the rock exactly over the side of the required hole. The heavy jumper, which worked through two cylinders, Fig. 1809, was a four-winged tool with a 6-in. leading point, the shaft being round and of 3 in. diameter; the total length 4 ft. 6 in. The jumper was further connected to upright rods of 2 in. round iron, screwed together in lengths. The top of the jumper rod was fastened to a shackle and chain which led over a pulley, placed upon the framework erected on the outrigger, exactly over the centre of the hole. A strong rope was taken from this chain through guide pulleys to a winch barrel, which was driven by a portable steam engine on the deck of the pier. Two men were stationed at *a*, with the ends of the ropes which were to lift the jumper coiled twice round the winch barrel. By hauling on the free end until the jumper rope had been drawn in 3 or 4 ft., and then suddenly surging or letting go, and steadily repeating the process, a constant rise and fall of the jumper was easily maintained through the cylinder on to the rock. An arrangement of bevel gear at the top of the jumper rods, enabled them to be slightly revolved from time to time at each occasion of the rising of the jumper.

When the jumper had entered to the required depth, and the hole was consequently complete, the tool was withdrawn and a pile lowered without difficulty into its place. The attendant diver then, through doorways made to open through the lower part of the cylinder, secured the pile in position, by means of the customary wrought-iron wedges and concrete. After the columns and brackets had been built on the piles, the joint rod of the cylinders was withdrawn; the cylinders then parted in halves, and were easily removed, to be employed again in a similar operation.

The effect of the bottom scour of the ground sea was often to fill up the hole with gravel, slough, and small pebbles, even faster than the jumper worked down; so that often a hole which was, say, 2 ft. deep in the morning would, after a day's steady work, be only 1 ft. deep in the evening, and, if jumping were suspended for two or three hours, would be entirely filled up.

The plan at last invariably adopted was, after starting a hole, not to stop day or night until it was completed.

Figs. 1810 to 1823 are of a floating pier and approach, designed by Robinson and Janson to suit the rise and fall of the tide, so as to allow at all times the easy and uninterrupted flow of traffic. The stage itself has no unusual feature about it. It consists of a platform resting on longitudinal wrought-iron girders, supported by wrought-iron pontoons, any one of which can be removed and repaired, or replaced by another, without in any way interfering with the traffic or the safety of the stage, and retained in position by mooring chains in the ordinary way. The longitudinal girders are of such a section and strength, as to secure a mean of the rise and fall of the innumerable small waves which attack the pontoons, and at the same time to leave to the stage such a degree of pliancy as in rough weather would allow it to partake of the wave motion of the water to relatively a small degree, and thus avoid unnecessary expense in the stiffness of the girders, or the danger that would follow from the stage being sometimes supported on the crests of a few waves at great distances apart.

One half of the stage is devoted to passenger traffic, and the other half to merchandise. The connection with the shore is by means of a floating bridge 420 ft. long and 33 ft. broad, divided in two by a handrail down the middle; so that passengers are kept to one side of it and goods to the other, as Figs. 1810, 1816. The bridge rises and falls with the tide, and consists of six 70-ft. lengths, joined together by universal joints, Figs, 1817 to 1823. Each length of 70 ft. is carried on two wrought-iron plate girders and a centre box girder, which are borne by two wrought-iron pontoons at each end of the span, moored in the same manner as the stage. At low water these pontoons settle down on gridirons, constructed of timber and screw piles, and at a gradient of 1 in 15; so that at the extreme low water the whole length of the roadway of the bridge will be at an inclination of 1 in 15. As the tide rises, part of it will be at this angle and part level. When the water rises to its extreme height of 32 ft., the first span from the shore will be in the position shown. All the gridirons are surrounded by paling supported by the outside piles, which are carried 5 ft. 3 in. above the level of the floor of the gridirons, as in the cross-section, Fig. 1821. This paling is for the purpose of acting as a breakwater, so that the pontoons may settle on their beds in calm water and without any concussion. Fig. 1813 is an elevation of the bridge and end view of the stage, showing how the bridge is constructed and carried by the pontoons; Fig. 1820 is a plan of the bridge for passengers and merchandise, and of the offices on stage and shore. Fig. 1816 is a plan of the gridirons of the same, and Fig. 1821 a cross-section through the bridge and one of the pontoons resting on its gridiron, also a view of the girders of the bridge. Figs. 1814, 1815, details of the attachment to the shore.

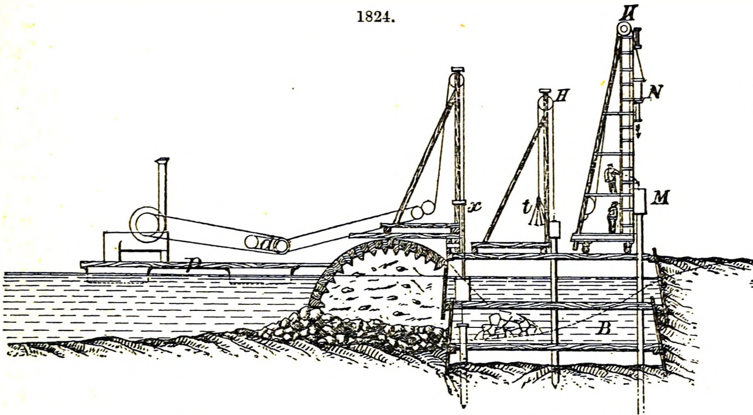
The whole of the wrought iron used for the work to which this design refers must be capable of bearing a tensile strain of at least 22 tons a sq. in. of section, without breaking; or of 16 tons a sq. in. with a permanent extension in length of not more than one sixty-fourth of an inch a foot.

See Bridge. Pile Driver.

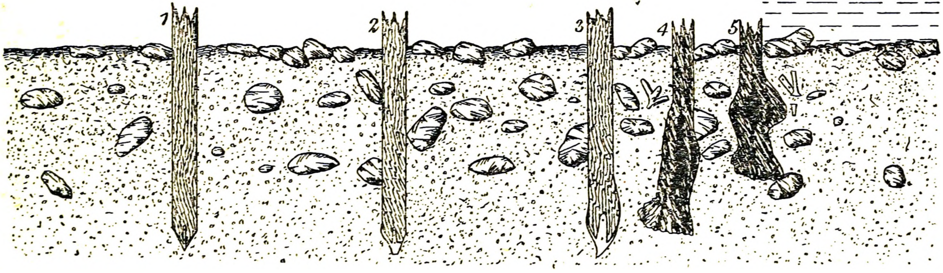
PILE DRIVER.

On the continent of Europe many economical and effective plans of driving piles have been devised, and amongst these an arrangement of steam pile-drivers by which several may be worked by one engine. The apparatus to the left of Fig. 1824 consists of three parts, a steam engine, which may be of any portable form ; an arrangement of grooved pulleys mounted on a wood frame, and termed a distributor, which is driven by the engine, and from which the several pile drivers are worked; and the pile drivers. All these may be placed in such varied positions as the circumstances of practice may dictate, as they are not connected except by the working and hauling ropes. Three pile drivers, worked from a distributor driven by one engine, were used for driving the Dresden Bridge piles. All or either of the pile drivers may be worked from this distributor at one time, or some may work while others are being shifted for driving other piles. This apparatus consists of a simple wood frame carrying a main shaft, worked by a strap from the engine. This same shaft carries three double-grooved pulleys d, over which run the ropes for driving the rope-winding barrels of the pile drivers. These pulleys are loose on the shaft, and all or any of them may be put into gear or fixed by means of clutches moved by levers.

1824.



1825.

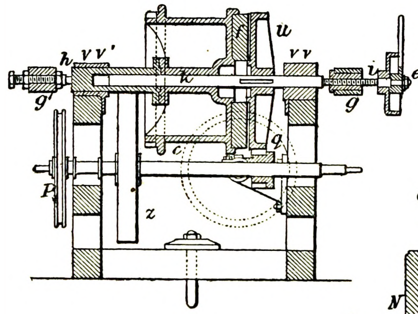


1826.

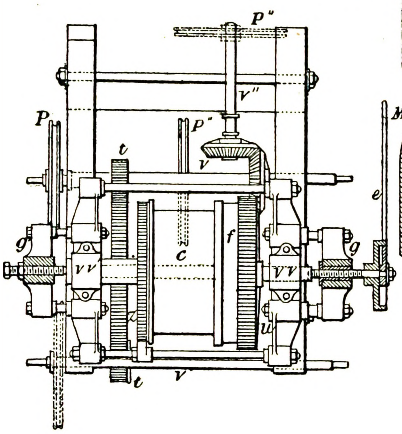
On the rear of the frame rails are fixed upon six beams, carrying small carriages supporting double-grooved loose pulleys, similar to d, and over the two sets of pulleys the pile driver ropes take a double turn, so that by means of weights suspended on chains, the carriages form a slack rope gear, by means of which the driving ropes are kept tight, during any small changes in the distance between the distributor and the pile driver. The driving ropes being double between the pulleys on the distributor, and single between them and the pile driver, a given moment in the carriages allows of twice that movement between the distributor and pile driver without stopping the apparatus. As the pile drivers are seldom opposite the pulleys d, guiding rollers are necessary, each double pair of these being mounted on vertical spindles, capable of a certain amount of motion in a vertical plane, and controlled by screws. By this arrangement the ropes are kept in the plane of the grooved pulleys d, and normal to the rollers, whatever their inclination beyond these.

The pile driver in general construction is similar to that in ordinary use, no other preparation being needed than a pair of timbers to receive the winding-gear frame. A cylindrical guide replaces the ordinary guides for the monkey, and besides being very simple, admits of working the latter below the level of driver. Figs. 1827, 1828 illustrate the winding gear by which the monkey is lifted. It consists of a wooden frame carrying double gear, by which the speed of the lifting rope is reduced to $\frac{1}{19}$ that of the distributor rope. On the shaft v, squared on the ends to receive handles, is fixed a grooved pulley P, over which runs the driving rope from the distributor. This pulley may be shifted to the positions p'' on the shafts v and v'', thus providing for changes in the relative positions of distributor and pile driver. The winding drum c, loose upon the shaft k, is driven by the spur wheel u, between the side of which and the drum is a disc of wood f, forming a friction clutch thrown in or out of gear by a quarter turn of the screw i and the lever e. To facilitate the removal of the pile driver, small rollers, carried in forked screwed stems, Fig. 1831, are fixed under each corner of the framing. The monkey employed weighed 1100 lb., the most effective mean fall being about 8 ft. 2½ in. The velocity of elevation of the monkey was 82 ft. a minute, so that the work done in lifting it, or the work of one pile driver $= \frac{82 \times 1100}{33,000} = 2 \cdot 73$ horse-power, or 8·19 for the three. The engine employed made 120 revolutions a minute, and was 7·92 nominal horse-power. It may be here noted that as all three of the monkeys would very seldom be lifting at one time, the horse-power actually required would be considerably less than that necessary for each machine, multiplied by the number of the latter. The work for driving the piles for the three caissons of the first pier for the bridge at Dresden, where an arrangement such as this was employed, commenced on the 27th of August, and terminated on the 2nd of September, 1875, after sixty-six hours' work, including the time occupied in mooring and fixing the plant.

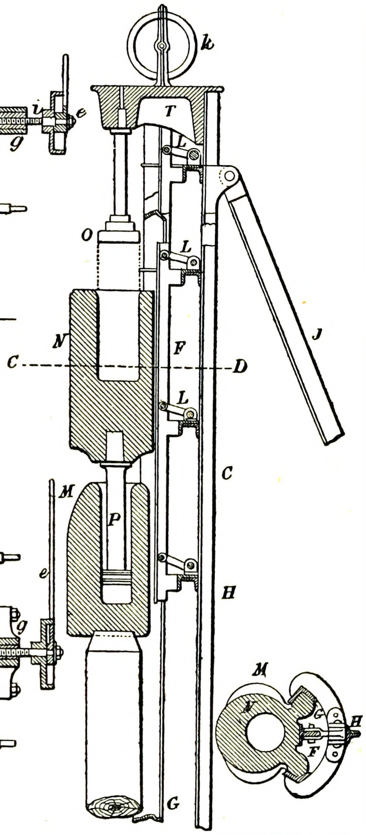
1827.



1828.



1829.



1830.

The work executed is detailed in Table 1;—

TABLE I.—PILES DRIVEN.

Number of Piles.	Diameter.	Length.	Length driven in Ground.	Total length driven.	Cubic Feet of Piles in Ground	Total cubic Feet in Ground.
	inches.	feet.	feet.	feet.		
70	11·81	29·52	592·50	..	450·0	..
21	9·84	29·52	89·50	..	47·3	..
15	7·87	23·0	59·00	740·50	26·8	524·1

Fig. 1832 is a diagram showing the rate of descent of the piles. The abscissæ represent the time 2 mm. to the minute, the ordinates a descent of 50 mm. to the meter.

The earth into which the piles were driven consists at the surface of compact gravel with large imbedded stones, and about a yard below the surface basalt and porphyry boulders of considerable size. These are shown in Fig. 1826, which will be hereafter referred to. The piles were shod with four-branch wrought-iron shoes, Fig. 1825, which weighed about 26·4 lb.; few of them came off, and none were broken in driving.

In Fig. 1826 at 1 is a normal pile, 2 one driven by hand, 3 steam-driven, 4 and 5 powder-driven.

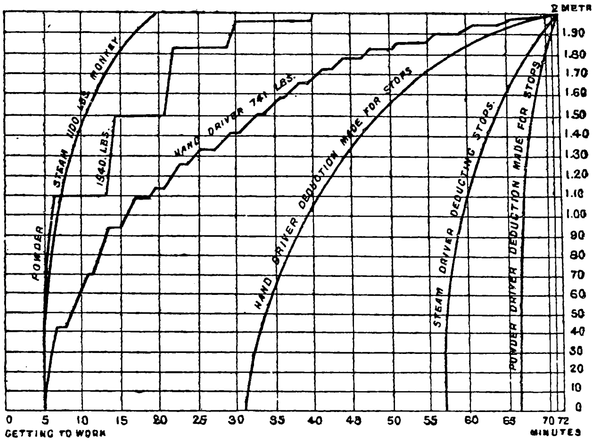
The apparatus described was employed in the construction of quays on the Elbe at Dresden-Altsdat, with the following results, the piles driven forming an enclosure with straight lines connected by curves of long radius. It was formed with 459 main piles from 13 ft. 1½ in. to 16 ft. 5 in. in length, and about 7·5 in. square; and 1631 intermediate piles of a mean length of about 13 ft., and 9·84 by 2·75 in. in section. The principal piles were driven from 5 ft. to about 7 ft. into the ground, and the intermediary or sheeting piles to about 3 ft. 11 in. The material driven into was about the same as that already described. The total quantity of piles driven into the ground amounted altogether to about 2685 cubic feet. The work was done by similar staff to that described above, and lasted thirty-two days of ten hours, or 320 hours for eleven men. The work done in cubic feet driven was;—

$$\text{Bridge, work an hour } \frac{513\cdot6}{66} = 7\cdot76 \text{ cubic ft.}$$

$$\text{Quays, work an hour } \frac{2683\cdot3}{320} = 8\cdot4 \text{ cubic ft.}$$

The monkey used for this sheet piling weighed about 900 lb., and the average fall was nearly 10 ft. Altogether about 120,000 blows were struck. This averaged forty-four blows a cubic foot of pile buried. The monkey was lifted at a velocity of 65·6 ft. a minute, the work of each pile driver being thus; 65·6 × 900 = 59,040 foot pounds, or 1·8 horse-power, or 5·4 horse-power for the three pile drivers. The engine employed had a cylinder 10·23 in. in diameter, with a stroke of 15·75 in. The steam used was at a pressure of three atmospheres cut off at one-third. It is remarked that by having three pile drivers arranged and suitably fixed to one pontoon of considerable size, each pile driver is much steadier, and the work can be better done than when only one pile driver is used, the tendency of each machine in work being to correct any swaying or motion caused by the others.

1831.



1832.

For driving piles in the construction of other bridges on the German rivers, ordinary pile drivers with monkeys guided in slides and released by a drop hook were used. Each was driven by a separate engine. The drums were put in or out of gear by a clutch lever, which also commanded the brake, and which prevented the chain wholly unwinding from the drum when the monkey dropped, and so causing a waste of time in re-winding.

The gunpowder pile-driver used on these works was Shaw's, modified by Reidinger. Figs. 1829, 1830 give the principal details, and the right of Fig. 1824 a general view. The frame is very strong, and of iron, supported on a turntable carriage, which may run on rails. The wheels may be easily taken off for fixing the apparatus on a pontoon. The principal part of the frame receives the monkey guides, and is made of vertical angle irons 5·1 in. by 3·5 in. by ·6 in., connected together by a cast-iron headpiece T, and held in a step casting at the bottom, capable of turning on the carriage so as to suit any given angle at which it may be desired to drive a pile. The two angle irons G G, forming the principal part of the frame, are connected by curved angle irons at about every 34 in. of the height of the frame, and these are connected together by a ┬ iron H. The principal part of the frame is held in equilibrium in the front by two angle irons 3·15 in. by 3·15 in. by ·47 in., bracing the head ┬ iron on the chariot. An I iron J, 5 in. by 3 in. by 47 in. (Fig. 1829), forms a brace, and constitutes a third-part of the frame. This is fixed at the rear part of the carriage by a bolt 1·5 in. in diameter. The monkey of the steam pile-driver is replaced by two separate pieces, the one, M, fixed on the pile is of cast steel, the other, N, of cast iron, sliding by projections cast thereon between guides G G. The part M carries similar projections, and fits in the same manner between the guides. This piece, called the mortar, is of elliptical section, and encircles the pile by a recess at the lower part. The bore is 6 in. diam. and 24·4 in. length. The monkey is also hollow at the upper part, the bore being 8·26 in. in diam. At the base is fixed a stem terminating in a piston fitting in the mortar M. From the crown T depends a second piston O, corresponding to the bore in the upper part of the monkey. The brake F for supporting the monkey is of ┬ iron, 3·5 in. by 2·36 in. by 2·36 in. by ·43 in. This ┬ iron is operated by levers L, forming a parallel motion and oscillating on the curved stays of the frame. The monkey is provided at the back with a surface which engages with the brake. Mortar and monkey can be raised separately or together by means of a chain over the pulley R, commanded by a windlass fixed on the brace J.

The principal dimensions of the pile are as follows;—Total height above rails, 37 ft. 1 in., length of carriage forming the base, 11 ft. 2 in.; width, 8 ft. 8 in.; width between rails, 8 ft. 2·75 in. Weight of monkey, 13 cwt. 3 qr. 3 lb.; weight of mortar, 15 cwt. 2 qr. 27 lb.; weight of carriage, 1 ton. 11 cwt. 3 qr. 6 lb.; weight of rest of frame, 2 tons 19 cwt. 5 lb.

The maximum dimensions of the piles which can be driven by this machine in compact gravel is 23 ft. in length and about 12 in. in diam. The explosive charge is made up in dry paper prepared at the works, the heaviest yet used being about 385 grains.

Two men are necessary to work the apparatus; one to attend to the brake and one to introduce the powder charge; and about six to eight men occupied in bringing and placing the piles, working the windlass, and removing the pile driver. The monkey being suspended at sufficient height, the man at the brake orders the introduction of the charge into the mortar, and then releases the monkey. The piston P compresses the air, which forms an elastic cushion under the pressure of from 20 to 25 atmospheres. A great elevation of the temperature of course follows, and the powder charge is thereby ignited, and the monkey again elevated by the powder gases and the compressed air. The work of raising the monkey is thus done upon the pile, as well as that of checking its descent after a given fall. It is said that the air cushion is effective in reducing the impact upon explosion, the pile being placed rather under a heavy pressure than receiving a severe shock. Fig. 1826, which is of some of the piles after being driven by the different means, suggests that the shock is much more severe than with the steam pile-driver. The pressure exerted by the gunpowder pile-driver upon the pile is composed of the following factors; the weight of the mortar, the compression of the air, the force of the explosion of the powder, the reaction due to the expansion of the gas during recoil, and the weight of the monkey—the action of which is inversely proportional to the resistance of the descent of the pile.

The operations connected with the application of the brake require an experienced hand and eye. If improperly worked the brake will check the ascent of the monkey to the fixed piston O. The operation is the affair of but four or five seconds, the command to fire is repeated, a second stroke follows, and this is repeated ten or fifteen times, after which a pause is made to grease the piston, clean the breech, and permit the cooling of the mortar. In experiments made by Hacquard, twenty strokes a minute with 308 grains of powder were seldom exceeded. With this number of strokes the mortar became so hot that the powder was liable to explode before the fair entry of the monkey piston, so that the proper effect of the explosion was lost, and the monkey had to be raised by hand windlass. The dilatation of the mortar also resulted, either in the non-explosion of the powder, because the air escaped past the piston instead of becoming compressed and heated, or else the powder gases escaped when the powder was fired by the heated air. The piston in these cases was very liable to suffer deformation. It is thus necessary that these tools should be placed only in the hands of careful men. Though in some respects this is objectionable, the mechanical work obtained, being the result of pressures and not of repeated shocks, does not produce on the framework the severe vibrations common, and which necessitate so much repair to pile drivers worked by steam on the Nasmyth principle. From these considerations the employment of gunpowder would seem not to be liable to the losses of time inherent with steam pile-drivers, for getting up steam, and their manipulation. Steam always requires the presence of the elements and tools for its production, while the powder is a simple motor, emmagazined, and always ready for action. For these reasons it is thought that it will be largely employed in the future, more particularly for light work.

At Dresden Bridge the apparatus was used more to obtain experimental results than for anything else, as it was known that the ground was not such as would give the best opportunity for successful work by this class of motor. It was therefore at first worked under conditions similar to those for working when driving piles in the bottom of an excavation, as indicated by Fig. 1826, whilst steam pile-drivers worked in the river. The excavation was for the foundation of a pier of 280 square metres of surface in a dam, also represented by Fig. 1823. It was at first cleared of the rocks, which prevented piling, and the work of sinking then performed by aid of waling board, battens, and pumping, to a depth of about 13 ft. below zero, when, the pump being insufficient, it was resolved to have recourse to piling and concreting the excavation. We have thus confined this description to three types of pile drivers, working under similar conditions as to the ground into which the piles were driven. These comparative results, and those obtained in the construction of the Mauthausen and Steyerreg bridges on the Danube, and those of Tetschen and of Aussig on the Elbe, with hand and steam pile-drivers are given in Table II.

The time occupied in driving a pile, which was on an average forty minutes, is thus analyzed;—Duration of effecting firing, five minutes; time occupied in stops for greasing, fifteen minutes; getting ready for driving, five minutes; stops necessitated by the passage of the public, fifteen minutes = forty minutes. The employment of powder in a town thus involved a loss of 37 per cent. of actual work. These conditions do not as largely affect the total cost as might be expected, because the constant, the powder, which represents the principal factor, about two-thirds the total expense, playing the principal part, it is necessary to seek its best application. To obtain this result, we have the comparison of the mechanical work, and the effective work in foot pounds for the different earths, and also the work of a grain of powder, from which we may deduce co-efficients, by the aid of which we can ascertain the charge of powder necessary for a given operation. It admits also of estimating the cost, and whether powder is applicable or not. In the case of the excavator at Dresden, the piles were 7·5 in. square, and armed with the same shoes. The mechanical work performed by the men working a bell-ringer pile-driver, and in driving the piles to a mean depth of 6·56 ft., was 145,807 foot pounds. For driving to the depth of 6·98 ft., as was the case with the powder machine, the work remaining sensibly proportional for the increased depth, the foot pounds will be $\frac{145,807 \times 6\cdot98}{6\cdot56} = 155,285$ foot pounds. The equivalent of one gramme—15·4 grains—was thus in this ground and under the given conditions $= \frac{155,285}{53 \times 20} =$ 146·5 foot pounds. From what will follow it will be seen that the mechanical effect of one gramme of powder should at least be doubled, for the apparatus is able to compete, as to cost of its work, with steam pile-drivers. As to the weight of the powder charge, experiments have shown that the total expenditure of powder diminishes proportionately as the weight used increases. From this it is concluded that the nearer the charge approaches the maximum limit, the nearer the most useful effect of the apparatus is approached. Given a mortar of sufficient strength, and a monkey corresponding, the maximum charge has only a limit in the limit of elasticity of the pile itself. Thus, in the case cited, the charge of 20 grammes—corresponding to the resistance of the mortar—gave 6 per cent. of ruptured piles, and determined for ordinary use the maximum charge for the pile as well as for the mortar. From this it results that the nature of the ground reacting more or less on the pile in opposing its descent is the principal factor which modifies the charges to be employed; for earths of little consistence the employment of powder in large charges gives a very high coefficient of useful effect, whilst in hard ground, permitting the use of but small charges, the useful effect may be very small indeed.

Table II.—Comparative Table of the Working of various Types of Pile Drivers.

Designation.	Bridges on the Elbe.					Bridges on the Danube.		
	Dresden. 1875.			Aussig. 1873.	Tetschen. 1874.	Mauthausen. 1869–70.	1870–71.	Steyerreg. 1872.
	Powder Pile-driver.	Combined Steam Apparatus.	Hand Pile-drivers.	Hand Windlass Pile-driver.	Single Steam Pile-driver.	Hand Windlass Pile-driver.	Single Steam Pile-driver.	Single Steam Pile-driver.
Position of the apparatus	On shore	On river	On shore	On river	On river	On shore	On stream	On stream
Mean velocity of current, in feet, per hour	..	4593	..	4920	4428	..	10170	9186
Height of pile driver, in feet	36	29·5	26·25	39·3	46	46	46	46
Weight of the monkey, in lb.	1540	1100	721	1320	1760	176	1760	1760
Depth of pile driven at first stroke, in inches	32	6	4	6	9·8	7	7·8	19·6
Depth of pile driven at last stroke, in inches	1·18	0·23	0·2	0	0	0	0	1·0
Number of piles observed	90	106	90	100	120	20	300	400
Weight of shoes, in lb.	13·2	26·4	13·2	16·6	16·5	33	33	16·5
Form of shoes	Four branches	Four branches	Four branches	Four branches	Four branches	Plain	Plain	Four branches
Dimensions at centre of pile, in inches	7·5 sq.	11·8 dia.	7·5 sq.	11·8 dia.	11·8 dia.	11·8 dia.	13·8 dia.	13·8 dia.
Length of piles, in feet	19·6	29·5	19·6	39·3	46	32·8	32·8	39·3
Mean depth each pile was driven, in feet	6·9	6·9	6·5	6·5	9·8	11·5	9·8	16·4
Cubic feet of the wood in the ground	2·71	5·0	2·71	5·0	7·5	12·5	10·18	17·1
Total length of piles buried, in feet..	629	741	590·5	..	..	..	..	..
Number of workmen	7	11	25	7	6	7	10	10
Mean number of piles driven per hour	1·40	1·60	0·84	0·4	0·35	0·20	0·50	0·50
Mean fall of the monkey, in feet ..	4·5	8·2	3·28	4·94	7·56	9·84	1·64	13·12

At Mauthausen, where beds of conglomerate, compact clay, with a rich bed of pyrites and gravel, with imbedded granite blocks, were passed through, the piles, 13·65 in. in diameter, were driven with a monkey weighing 1760 lb., and with rapid strokes not exceeding 19·6 in. At Steyerreg, on the contrary, where the earth was heterogeneous, the height of fall sometimes reached 16 ft. with the same pile driver, and gave them very good results. Great importance attaches to the proper form and mode of fixture of the shoe. The ends of the pile should with great care be cut quite square, and the lower end nicely fitted on the flat part of the shoe. The spike holes by which the latter is attached should be as shown in Fig. 1825. We do not see the necessity for leaving much play if the spikes are properly driven so as to pull the shoe tight up to the bottom of the pile, especially if the shoe is properly fitted. The powder pile-driver can be most successfully used in homogeneous earths not of a hard character, such as peaty, argillaceous, or sandy ground, as it is only in these that the larger and the more economical charges of powder can be used.

Fig. 1829 is interesting as showing the condition of different piles after driving by the various machines into the kind of material described. The two illustrations of the powder-driven piles are of course of abnormal cases, but it is fully evident that powder cannot be used for driving in hard ground with interspersed boulders.

The experiments with gunpowder described took place in hard ground much disturbed—see Figs. 1824 and 1826. We shall now see the apparatus under more favourable conditions.

The Gunpowder Pile-driver driving Piles into Soft Ground at Wilhelmshafen.—For the recent works at the port of Wilhelmshafen an apparatus similar to that just described—but more powerful, the weight of the monkey being 2552 lb., and that of the mortar being 2090 lb.—was employed by the side of a steam pile-driver on Nasmyth's principle. The ground was composed of clay or loam, argillaceous sand, and lastly, fine sand. Table III. gives the comparative results obtained;—

The results given in this table show that the experiments proved the work of the powder driver is, in hard earth with large imbedded stones, much more expensive than that of the steam machine. Fig. 1826 illustrates the aspect of the piers in the different cases after driving. After examining these, taken from the actual piles, it will be remarked that by reason of the rapid action of the powder the earth has not time to become displaced, and that such obstacles as can be pushed aside by light repeated strokes break the shoes off and split the piles, which can be driven no farther. The piles in this condition are indicated in two cases by Fig. 1826. In the case of the steam apparatus, we may learn by the nature of the blow and the driving it produces, the value of the resistances which normally present themselves, and may accordingly vary the height of the fall of the monkey, so as not to break the shoe.

Table III.—Comparison of Gunpowder and Steam Pile-drivers.

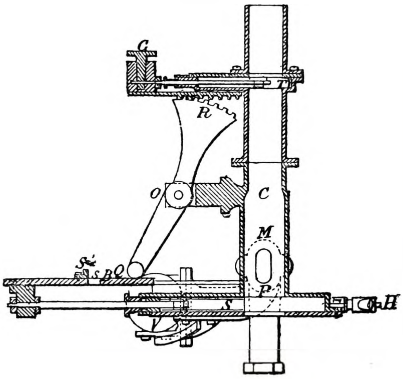
Description.	Powder.	Steam.
Total weight of apparatus	10·165 tons	24·55 tons
Time during which apparatus stood	3 days	14
Persons employed	8	12
Number of piles observed	9	1885
Length of piles	32·8 ft.	32·8 ft.
Diameter of piles	11·8 in.	11·8 in.
Depth driven	28·2 ft.	29·5 ft.
Cubic total of wood driven below ground	211·8 ft.	459 ft.
Total length of piles driven in feet	253·8	55·6
Duration of work	345 minutes	116 days
Mean number of piles driven in twelve hours	19	16
Number of strokes of the monkey a minute	6	5 to 6
Ditto a foot cube	·7 to ·85	13·
Ditto a foot run	·3 to ·6	9
Ditto each pile	18 to 20	250

PNEUMATIC TRANSMISSION.

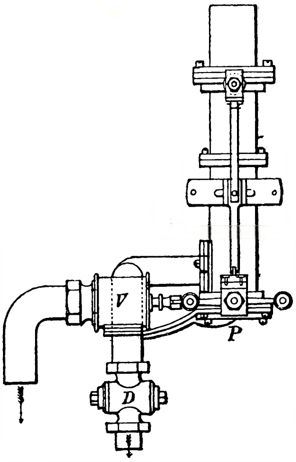
The transmission of goods and passengers by a railway worked either by exhaustion or compression of air was at one time a favourite project with engineers, and several short lines were constructed upon this principle. They were not, however, found to be economical, and have fallen into disuse for any purpose except the transmission of small parcels, letters, and especially telegrams. For the latter purpose, the transmission of telegrams between two main and out stations of large cities, the system is of great service. The plans upon which it is worked are fairly represented by those in use in London and in Paris. In the London system, for the description of which we are indebted to a paper by R. Sabine and R. S. Culley, M.I.C.E., 1876, the pneumatic tubes, which are laid double, are worked from one centre, namely, the central station in the General Post Office, at which point the engines and air pumps are fixed. At that station the tubes are arranged vertically, side by side, and each is terminated by a valve. Those used exclusively for forwarding messages, are situated at one end of a long table; those used both for forwarding and receiving, in the centre; and those for receiving only, at the other end. The messages for delivery by hand are sent through a tube to the room below, and there are several tubes for conveying messages to different parts of the gallery.

The Varley valves adopted at the first in the London system, though efficient, are expensive in first cost, and troublesome to keep in order, because of their complexity. In providing for a system so large as that of the English Post Office, it became necessary to devise a simpler arrangement, and the valves employed admit of each tube being used either exclusively for sending carriers to a distant station by means of compressed air; or exclusively for receiving carriers by means of vacuum; or for sending or receiving at pleasure on the same tube. Fig. 1834 is a section, Fig. 1833 a plan, and Fig. 1835 a back view of the valve. In sending, the carrier containing the messages is inserted into the chamber M, Fig. 1833, until it is held by the contraction at C, where the chamber narrows to the size of the tube. The handle H is next drawn forward, carrying with it the sluice S, which closes the mouth P of the chamber. The top S′ now strikes the lower end of the lever O Q, pressing it into the slot *s* of the sliding bar B, and the continuation of the motion opens the upper

1833.

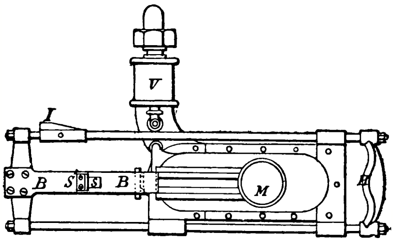


1835.



slide T by means of the rack R. At the same time the inclined plane I, Fig. 1834, attached to one of the sliding rods actuating the lower sluice S, passes between a fixed roller and a roller fitted to the valve V, establishing communication between the pressure main and the message chamber, the compressed air expands the felt casing of the carrier, causes it to fit the tube, and forces the carrier forward. On its arrival being signalled electrically, the handle H, Fig. 1834, is pushed inwards, the air cut off, and the message chamber opened ready for another carrier. The operations of opening and closing the slide occupy so short a time, and the resistance of the long pipe is so great, that if it be desired to send a second carrier before the first has reached its destination, the speed of the first is not sensibly affected. The cock D, Fig. 1835, connected with the vacuum main is closed. By closing the top sluice before opening the lower one the rush of compressed air from the tube is prevented.

1834.



In receiving, the carrier is inserted at the distant end of the pipe, and is signalled. On receipt of the signal the lower sluice is closed, and the upper one is opened as before. Communication with the vacuum main is now established by opening the cock D, Fig. 1835, and when the arrival of the carrier is known by its striking the lower sluice S, Fig. 1833, or by observing it through a glazed opening in the message chamber, the vacuum is shut off by the cock D, and the handle H is pushed in. The top sluice being now closed, and the lower one opened, the carrier, having passed the contracted part C, drops out. The connection between the valve V, and the pressure main is cut off by a cock on the pipe E, Fig. 1835, not shown. Here again the operations of removing the carrier and of turning on the vacuum do not sensibly affect a following carrier.

In sending or receiving on the same tube, the upper sluice T, Fig. 1833, is thrown out of use by removing the plug G, which connects it with the rack R, and the quadrant; it is opened and held back by a clamp. The manipulation is the same as before, except that in sending, after the carrier has arrived, the slide is at first pushed back only far enough to close the pressure valve V, so as to give the compressed air time to expand in the pipe before the lower sluice is opened. This prevents the noise of escaping air. In receiving, care must be taken not to move the handle so far as to open the pressure valve V.

At the out-stations, the tubes terminate in a glass box, with a swinging door opening inwards. The door is closed by the pressure of the incoming air, and the air itself escapes through a pipe fitted at the bottom of the box: were it not for this provision the out-stations would be filled with air which had passed through the pumps. This pipe serves also as a drain to carry off the water used to clear obstructions in the tube. The message tube is fitted into the top of the box, so that nothing can fall into it accidentally. Intermediate stations are fitted with the rocking sluice.

Lead has been used in every case except for the two tubes between Telegraph Street and Charing Cross, which are of iron. These iron tubes have been very troublesome. The lead tubes are very slightly damp, and no inconvenience has ever arisen from that cause. In Paris, although the tubes are of iron, they do not rust, but little vapour of water is passed through them, and condensation scarcely occurs. Besides this, the tubes are kept clean by the friction of the heavy pistons which pass through them. The lead does not appear to wear at all, except in places where the pipe has been accidentally indented.

The employment of lead instead of iron for the extension of the system is to be recommended. It has been shown to be practically indestructible, the joints of the pipe are easily made perfectly air-tight; it becomes polished by use, thereby reducing friction and the wear and tear of carriers. Iron, on the other hand, has been found to rust very quickly, and to destroy the carriers.

It was proved conclusively by experiment that, with equal lengths, working with equal pressures, the times of transit of carriers through three sizes of lead tubes were in the following proportion;—

Through a 3 inch tube	.. ..	100
„ $2\frac{1}{4}$ „	.. ..	116
„ $1\frac{1}{2}$ „	.. ..	141

and that to effect the transits in those times the power required would be;

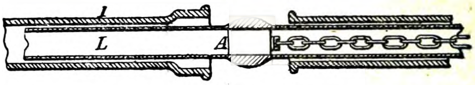
For the 3 inch tube	.. ..	100
„ $2\frac{1}{4}$ „	.. ..	49
„ $1\frac{1}{2}$ „	.. ..	18

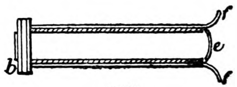
For the long lines contemplated it was, however, deemed inadvisable to use tubes of such small diameter as $1\frac{1}{2}$ in., and as the time saved by a 3-inch tube was proved to be small in comparison with the extra engine power required to work it, it was decided to employ $2\frac{1}{4}$-in. tubes for all the new lines. The exact internal diameter of the whole lead tubes is $2\frac{3}{16}$ in.

The tubes are made in lengths of about 29 ft. Each length is laid in a wooden trough as soon as it is manufactured, so that it may be handled without fear of bending. A tightly-fitting polished steel mandril, attached to a strong chain, is then drawn through it, to ensure the pipe being smooth, cylindrical, and uniform throughout. It is necessary that the mandril should be lubricated with soft soap, so that it may not injure the pipe. When laid, the leaden tubes are protected by being enclosed in ordinary cast-iron pipes.

The leaden tubes, straight and smoothed, are delivered from the wooden troughs to the trench prepared to receive them. The iron pipes I, Fig. 1836, are then drawn over the lead, leaving enough of the leaden pipe L projecting to enable a plumber's joint to be made; a strong chain is next passed through the length of tube to be joined on, and a polished mandril A, being heated and attached to this chain, is pushed half its length into the end of the pipe. The new length of tube is then forced over the projecting end of the mandril, so that the leaden tubes, the ends of which have been already cut flat by an apparatus made for the purpose, butt perfectly together, and a plumber's joint is made in the usual manner. The tube is thus air-tight, and the mandril keeps the surface of the tube under the joint as smooth as at any other part of its length. After the soldering process has been completed, the mandril is drawn out by the chain attached to it; the next length is drawn on, and the process repeated. Where it is necessary to deviate from a straight line, it is essential that the tubes be laid in a circular arc, whose radius shall not be less than 12 ft. The same care is necessary in entering the various stations, otherwise undue friction will arise, and curves would be introduced which might cause the carrier to stick fast.

1836.





1837.

The carriers or pistons consist of a cylindrical box of guttapercha, Fig. 1837, covered with felt or drugget. The felt is allowed to project beyond the open end of the carrier in the rear, as shown at *f*, *f*, so that the pressure behind causes this portion to expand and to fit the pipe exactly. The front of the carrier is provided with a buffer *b*, formed of several pieces of felt, which just fits the leaden pipe. To prevent the messages getting out of the carrier, the end is closed by an elastic band *e*, which can be stretched sufficiently to allow the messages to be put in. The weight of a service carrier is $2\frac{3}{4}$ ounces avoirdupois. Leather has been tried, and although, if properly prepared, it answers well for iron, it is unsuitable for lead. The object in England has been to lessen the weight of the carrier as much as possible; but in Paris the mean weight of a train, consisting of a piston, called the locomotive, and five carriers of iron covered with leather, is 6·6 lb.

Electric signals are used between the central station and the outlying stations, consisting of a single-stroke bell with indicator, to give notice of the departure and arrival of carriers, and to answer the necessary questions required in working.

When there are intermediate stations the tube is worked on the block system, as if it were a railway. Experience shows that where great exactness in manipulation cannot be obtained, it is necessary to allow only one train in each section of a tube, whether worked by vacuum or by pressure. But where there is no intermediate station, and where the tube can be carefully worked, carriers may be allowed to follow one another at short intervals in a tube worked by vacuum, although it is not perfectly safe to do so in one worked by pressure. In working by pressure it has been found that, notwithstanding a fair interval may be allowed, carriers are apt to overtake one another. For no two carriers travel in the same times, because of differences in fit, unless they are placed end to end. If signalling be neglected, and a carrier happens to stick fast, being followed by several others, a block will ensue, which it will be difficult to clear, while the single carrier could readily have been dislodged. Provided due care be exercised in the construction of the work, interruptions of the service are of rare occurrence, except from neglected signalling.

When carriers stick fast in the pipes, and cannot be moved either by compressing or by exhausting the air, the pipe is flooded with water, and the carriers forced past the obstruction by increased pressure. The water flows off by the drain-pipe at the distant station. All tubes are now fitted with a small pipe by which water may be admitted if necessary. As stoppages have been so infrequent, it has not been necessary to devise any very elaborate means of discovering the locality of a fault. An approximate idea may be formed from the time the tube takes to discharge itself when filled with compressed air; and when the fault is not too distant from either end, the simple expedient of measuring by means of string attached to a carrier has been found sufficient. It has never been requisite to open a lead pipe to remove a carrier stopped by any other cause than imperfect construction or external injury, the position of which was known. The iron pipes have been more troublesome.

As a rule, on the Continent of Europe, each pneumatic line comprises several stations, this being the most economical arrangement as regards first cost. In some cases the tubes form a continuous circular line, in which the trains or carriers travel in one direction only; the stations becoming either the starting-points of fresh circles, or of direct single lines. In Paris the greater part of the stations are grouped in circles, but power is provided at every station so that each section makes a distinct line. By these means the transit is considerably accelerated, but at a great cost. The line between the Bourse and the central station is direct, and two, sometimes three, carriers are permitted to follow one another; but on the circular lines the trains only run every fifteen minutes, so that a comparatively small pumping power is required, there being time for accumulation. The delay arising from this system would be fatal to the traffic of large towns in Great Britain, for it is obvious that if a message arrive but a second after a train has started, it may be twenty, or even twenty-five minutes in reaching its destination, even if lying in the same circle. Nor can many stations be included in the same circuit, but the communication between the central station and the more important branch or out-stations must be direct.

The public is perhaps exacting in its demands for speed, and never thinks of the cost. To conduct the message traffic with the despatch demanded, every cause of delay, however small, must be eliminated, whether it occur in the transfer from the receiving office to the instrument room, on the wire itself, in the delivery, or in the pneumatic tube. A delay of even ten minutes would be fatal to the Metropolitan traffic, so that where this limit is approached the tube must be replaced by the wire. Now when the same tube serves two out-stations, the time occupied by the carrier in running from the central to the nearer station is increased by the addition of the tube to the farther station. Other causes of delay are also introduced; for instance, that of sorting the messages, and of removing at the intermediate station those intended for that station. In a circular system, including several stations worked with a continuous current of air, the tube is still further lengthened, and the speed reduced. There is also this inconvenience; if A, B, C, and D are four out-stations, connected by a circular tube starting from and terminating at the central office, and if the direction of the air current is from A to D, then a message from the central office to D must pass through almost the entire tube, subject to the diminution of speed due to the lengthened tube, and to the delay caused by the arrangements for working the more complicated system. Where despatch is not of paramount importance, the circular system has advantages, by giving communication betweeen each station on the route. In London, however, the traffic is almost entirely to and from the central station.

The transmission of a carrier from one end of a tube to the other, is effected by the expansion of the denser air, which enters the tube during the interval between the moment of starting and the moment of exit of the carrier.

In pressure-working, each transit costs exactly the force necessary to produce this volume of compressed air, whilst in vacuum-working each transit costs the force necessary to expand a corresponding volume of air at atmospheric pressure. This is obviously the case, because when the carrier arrives at the end of its journey, the tube has been filled behind it with just this volume of air at the higher pressure; and this volume is less than the whole volume of the tube by just so much as the air has expanded.

The absolute work F, stored up in a unit volume of air at the effective pressure h, is that exerted to compress it from p_2 to p_1, or that which it will return in expanding from p_1 to p_2, through the distance y, as has been already shown by Zeuner.

$$F = \int_{p_1}^{p_2} p\,d\,x;$$

$$\frac{p}{p_1} = \left(\frac{1}{x}\right)^n \therefore p = p_1\,x^{-n} \;\therefore x = \left(\frac{p_1}{p}\right)^{\frac{1}{n}};$$

$$F = \int_{p_1}^{p_2} p_1\,d\,x\,x^{-n} = \frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{1-n}{n}}\right\}; \qquad (1)$$

in which $n = 1{\cdot}408$, the relation between the specific heat of dry air, when maintained at a constant pressure and when maintained at a constant volume. For 1 cub. ft. of air at p_1, the work f, effected by it in expanding in the tube to p_2, is therefore

$$f = \frac{144\,p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} \;\ldots\ldots \text{foot lb.};$$

p_1 and p_2 being in lb. a square inch, assuming that the air in expanding does not take up any heat through contact with the tube.

Inserting the numerical value of n, the work of 1 cub. ft. becomes

$$f = 352{\cdot}9\,p_1\left\{\left(1 - \frac{p_2}{p_1}\right)^{0{\cdot}29}\right\} \;\ldots\ldots \text{foot lb. [log. } 352{\cdot}9 = 2{\cdot}54770\text{]}; \qquad (2)$$

p_1 is always the greater pressure, and p_2 the lesser.

When pneumatic tubes are worked with compressed air, p_2 is atmospheric pressure (14·75); but when worked with vacuum, p_1 becomes the atmospheric pressure.

Air passing through a tube expands as it goes on from the higher to the lower pressure, the expansion being nearly regular. Supposing that it neither gives to, nor takes from, the surface of the tube any heat, it would follow from the above that

$$\frac{s_1}{s_2} - \frac{v_1}{v_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{n}};$$

s_1 being the velocity and v_1 the volume of the air as it enters, and s_2 the speed and v_2 the volume as it leaves the tube, p_1 the higher and p_2 the lower pressure.

Then if it be assumed that the pressure in the middle of the tube is a mean of the pressure at the ends, the velocity of entry of the denser air and the volume of it which enters between the starting and exit will be respectively

$$s_1 = s\left(\frac{p_1 + p_2}{2\,p_1}\right)^{\frac{1}{n}}, \qquad (3)$$

and

$$v_1 = v\left(\frac{p_1 + p_2}{2\,p_1}\right)^{\frac{1}{n}}. \qquad (4)$$

The effective work stored up in the denser air which enters the tube during the transit is expended in accelerating the speed of the carrier and the air, and in overcoming their frictions against the sides of the tube.

The work A, expended in accelerating the air will be

$$A = \frac{w\,v\,s_2^{\,2}}{2\,g} \;\ldots\ldots \text{foot lb.}; \qquad (5)$$

s_2 being the velocity of greatest motion, and g the terrestrial acceleratrix $= 32{\cdot}2$, both in feet a second, and w the mean weight of the whole of the air which moves in the tube during the transit, in lb. a cubic foot.

If the weight of the carrier in the tube be W lb., the work, B, of acceleration is

$$B = W\frac{s_2^2}{2g} \; .\;.\;.\;. \text{ foot lb.} \qquad (6)$$

After allowing for the work spent in acceleration of the air and of the carrier, the remaining work applied to propel them is, of course, consumed in overcoming their resistances to motion. The mechanical effect, C, absorbed by resistance to motion of air in passing through a tube of the length l feet, and diameter d feet, has been found to increase directly as the length and inversely as the diameter of the tube.

$$C = \xi\frac{l}{d}\,.\,w v\,.\,\frac{s^2}{2g} \; .\;.\;.\;. \text{ foot lb.;} \qquad (7)$$

s being the mean velocity of the air in the tube.

The expenditure of power in overcoming the resistance of air to motion is more important than any of the rest, amounting in general to at least ten times all the others put together. There exists no definite and satisfactory determination of the value of the constant of friction ξ, which probably varies slightly, not only with the diameter, the material, and the condition of the surface of the tube, but likewise with the density of the air which is passing through. Experiments to determine its value have been made by Girard, D'Aubuisson, Buff, Pecqueur, and others, who give a mean value to it of 0·02. This value agrees with experiments with the lead tubes laid down in London, which are worked with felt carriers, and which have become to a great extent polished by continual passage to and fro. For the lengths of iron tubes, which appear, from the wear and tear of the felt carriers, to be exceedingly rough and wet, the value of this constant, ξ, appears to be about 0·028 or 0·03.

Lastly, the work D, consumed in friction of the carrier is

$$D = \mu W l \; .\;.\;.\;. \text{ foot lb.,} \qquad (8)$$

in which μ is the coefficient of friction to motion between the material of the carrier and that of the tube. In some experiments with felt carriers it was found that the average weight was 2¾ oz., and that the friction to motion when in the tube was 1¾ oz. The value $v_1 \times f$ foot lb. of work is therefore balanced by the items of expenditure (A + B + C + D), or $v_1 f = A + B + C + D$, in which v_1 = volume of denser air which enters the tube during the transit.

Setting the algebraical values in this equation

$$v f \left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{n}} = \frac{w_2 v s_2^2}{2g} + \frac{W s_2^2}{2g} + \xi\frac{l}{d}\frac{w v s^2}{2g} + \mu W l.$$

From which is obtained the mean velocity s, with which the carrier travels—

$$s = \sqrt{2g\frac{v_1 f - \mu W l}{\left(\frac{p_1 + p_2}{2 p_2}\right)^{\frac{2}{n}} (W + w_2 v) + \xi\frac{l}{d} w v.}} \; .\;.\;.\;. \text{ feet a sec.} \qquad (9)$$

In practice the friction of a dry carrier in a polished metal tube is so little, and the weight is so trifling, that both may be omitted without appreciable error.

The last equation then takes the form

$$s = \sqrt{2g\frac{f\left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{n}}}{w\left(\frac{p_1 + p_2}{2 p_2}\right)^{\frac{2}{n}} + \xi\frac{l}{d} w}} \; .\;.\;.\;. \text{ feet a sec.}$$

And when the tubes are very long in comparison with their diameters, that is to say, when the length exceeds 5000 times the diameter, in practice the formula may be written thus;

$$s = \sqrt{2g\frac{f\left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{n}}}{\xi\frac{l}{d} w}} \; .\;.\;.\;. \text{ feet a sec.;} \qquad (10)$$

or numerical constants inserted for lead tubes;

$$s = 56{\cdot}7\left(\frac{d}{l}\right)\left(\frac{f}{w}\right)^{\frac{1}{2}}\left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{2n}} \; .\;.\;.\;. \text{ feet a sec.} \quad [\log.\ 56{\cdot}7 = 1{\cdot}75375], \qquad (11)$$

which is equivalent to neglecting altogether acceleration and also friction of the carrier. In other words, for light carriers moving in polished tubes, the air is assumed to move with the same velocity whether a carrier is in the tube or not.

The time occupied by the carrier in passing from one end to the other is

$$t = \frac{l}{s} \; .\;.\;.\;. \text{ seconds;}$$

therefore, for lead tubes,

$$t = 0{\cdot}0176\left(\frac{w}{f}\right)^{\frac{1}{2}}\frac{l^{1\cdot5}}{d^{0\cdot5}}\left(\frac{2 p_1}{p_1 + p_2}\right)^{\frac{1}{\;}} \; .\;.\;.\;. \text{ seconds.} \quad [\log.\ 0{\cdot}0176 = \bar{2}{\cdot}24625]. \qquad (12)$$

The weight of a cubic foot of air at 20° Cent. is 0·07533 lb. at mean barometric pressure.

If the pressure p_1 lb. a square inch acting on a body of air, each cubic foot of which weighs w_1 lb., be suddenly changed to p_2 lb., the weight of a cubic foot will be changed to w_2 lb.

$$w_2 = w_1 \left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} \ldots \text{lb.} \qquad (13)$$

If before the transit of a carrier the pressure at each point in a tube corresponds with the flow of air due to the end pressures, as in continuous working, and if during the transit the latter are kept constant, the mean specific weight w of all the air may be assumed to be practically

$$w = \frac{w_1 + w_2}{2} \ldots \text{lb.} \qquad (14)$$

But if, as in intermittent working, the tube, to begin with, be filled with air at atmospheric pressure, the mean will be lower or higher than the mean corresponding with the end pressures, according as the tube is worked with pressure or with vacuum. For pressure-working the mean specific weight may be then taken as

$$w = \frac{w_1 + 3\,w_2}{4} \ldots \text{lb.} \qquad (15)$$

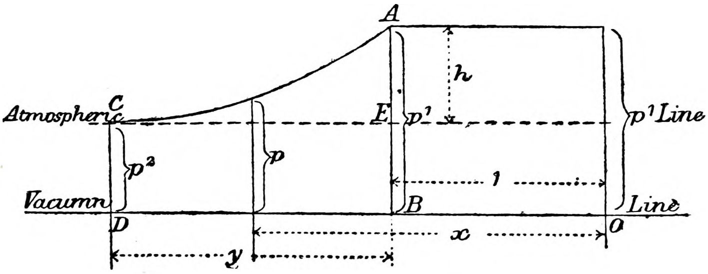
For vacuum-working,

$$w = \frac{3\,w_1 + w_2}{4} \ldots \text{lb.} \qquad (16)$$

These mean values, it should be understood, are only approximations, the actual specific weights being affected to a great extent by accidental causes, such as the temperature of the tube, the resistance offered by curves, and the like.

To ascertain the work done in maintaining compressed air in the main or container, let the stroke of the piston of the pressure pump be from D to O, Fig. 1838; let the pressure of the atmosphere with which the cylinder is filled at the commencement of the stroke be p_2; let the required effective pressure h, actual pressure $= h + p_2 = p_1$, be reached when the piston arrives at B; and let the piston, in travelling the remaining distance B O, transfer the compressed air from the cylinder into the container.

1838.



The air at the commencement of the stroke is already compressed to what is called atmospheric pressure, therefore each cubic foot already contains a certain potential energy, which is the work it would exert fully if expanded into an absolute vacuum.

When the air is further compressed its potential energy is increased, and the difference between the two potentials is the work it can perform in expanding between the two pressures. This difference of potentials, or aeromotive power, is represented by the area A B C D, of which the area B D C E has been done by the superincumbent atmosphere, and must be subtracted from the whole energy of the unit volume of compressed air between the two pressures, in order to find the effective energy which the compression costs. In other words, when a cubic foot of compressed air has been produced by a pump, the pump has not done all the work which is stored up in it, because the greater part of this work has usually been done by the pressure of the atmosphere.

The absolute work F is represented by the area A B D C.

The effective work by the area A B D C − B D C E = A E C.

The absolute work F is by formula 1,

$$\mathrm{F} = \frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} \ldots \text{foot lb.}$$

and since

$$p_2\,(y+1)^n = p_1,$$

the length

$$y = \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\},$$

and the area E B D C; the work done by the atmosphere is

$$y\,p_2 = \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\}p_2.$$

Therefore the effective work done in compression by the pump is

$$\mathrm{F} - y\,p_2 = \frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} - \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\}p_2. \qquad (17)$$

Now this difference is the work which has been performed in driving the piston only to the point B, that is to say, until the air has reached the required pressure p_1. It has still, however, to be driven into the container, and to do this the force h lb. must be exerted through the distance 1.

For each cubic foot of compressed air, therefore,
the absolute work done, f, is:—

$$f = 144 \left[\frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\}\right] \ldots \text{ foot lb.}$$

The work done by the atmosphere $= a = 144\left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\}p_2$ foot lb.

Difference of these = the effective work done in compressing $(f - a)$.

Work done in driving compressed air into container $= 144\,h$.

Total amount of effective work E, done after forcing into the main 1 cub. ft. of compressed air =

$$\mathrm{E} = f - a + 144\,h \ldots \text{ foot lb.,}$$

or

$$\mathrm{E} = 144\left[\frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} - \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\}p_2 + h\right]; \qquad (18)$$

with the numerical values of constants inserted—

$$353\,p_1\left\{1 - \left(\frac{14{\cdot}75}{p_1}\right)^{\cdot 29}\right\} - 2124\left\{\left(\frac{p_1}{14{\cdot}75}\right)^{\cdot 71} - 1\right\} + 144\,h \text{ foot lb.}$$

The engine power required for each cubic foot, a minute, of compressed air maintained in the main or container at an actual pressure p_1 is therefore

$$\frac{f - a + 144\,h}{33000} \ldots \text{ H.P.}$$

If in a tube, whose diameter is d feet, the mean speed of a carrier is s feet a second, the volume of compressed air required a minute will be

$$0{\cdot}7854\,d^2 \times 60\,s \times \left(\frac{p_1 + p_2}{2p_1}\right)^{\frac{1}{n}} \ldots \text{ cubic feet.} \qquad (19)$$

And the engine power required to do this is

$$\frac{f - a + 144\,h}{33000} \times (0{\cdot}7854\,d^2 \times 60\,s) \times \left(\frac{p_1 + p_2}{2p_1}\right)^{\frac{1}{n}} \ldots \text{ H.P.} \qquad (20)$$

The operations of the vacuum pump are similar.

When the air in the main has once arrived at the state of rarefaction at which it is employed, the lines connected with it admit a continued flow of air, which expands as it comes along to the tubes, and enters the pump with nearly the larger bulk due to its diminished pressure. The problem, therefore, resolves itself into compressing this expanded air again to the pressure of the atmosphere, and delivering from the pump the same weight of air a minute as that which under atmospheric pressure enters the tubes at their farther ends.

The effective work E′ required for each cubic foot a minute of air entering at atmospheric pressure is therefore

$$\mathrm{E}' = 144\left[36{\cdot}1\left\{1 - \left(\frac{p_2}{14{\cdot}7}\right)^{\cdot 29}\right\} - p_2\left\{\left(\frac{14{\cdot}7}{p_2}\right)^{\cdot 71} - 1\right\} + h\right] \ldots \text{ foot lb.}$$

If the mean speed of a carrier is s feet a second in a tube whose diameter is d feet, the volume of atmospheric air a minute admitted at the farther end is

$$\mathrm{V}_1 = 0{\cdot}7854\,d^2 + 60\,s \times \left(\frac{p_1 + p_2}{2\,p_1}\right)^{\frac{1}{n}} \ldots \text{ cubic feet.}$$

The engine power required a minute for this tube is therefore

$$\frac{\mathrm{E}' \times \mathrm{V}_1}{33000} \ldots \text{ H.P.} \qquad (21)$$

and the engine power calculated from the volume of expanded air is

$$\frac{\mathrm{E}'\,\mathrm{V}_2\left(\frac{p_2}{14{\cdot}7}\right)^{\cdot 71}}{33000} \ldots \text{ H.P.} \qquad (22)$$

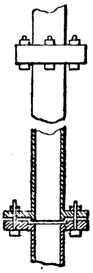
The volume a minute, at the effective vacuum h, actual pressure h, as it passes through the main and the vacuum-pump, on the assumption that it does not become heated from contact with the tube, being

$$\mathrm{V}_2 = 0{\cdot}7854\,d^2 \times 60\,s \times \left(\frac{p_1 + p_2}{2\,p_2}\right)^{\frac{1}{n}} \ldots \text{ cubic feet.}$$

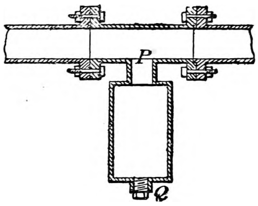
The tubes employed in the Paris pneumatic system, to which we have already briefly referred, are of wrought iron, in lengths of from 15 ft. to 20 ft., the joints being made by means of flanges and bolts, as in Fig. 1839. The interior diameter of the tube is 2·559 in., with a maximum variation to 2·519 in. The curved portions have radii varying from 30 ft. to 150 ft., and the proportion of curved to straight is about one-seventh. The tubes are laid in the ground at an average depth of 39 in., and with but slight inclines, except at the stations, where the tube enters at the basement, and is curved upwards, with a radius of from 6 ft. to 18 ft., and terminates vertically to adapt itself to the receiving and transmitting apparatus. Where possible the tubes are laid in the subway under the streets, against the sides of which they are supported by brackets 5 ft. or 6 ft. apart.

Water frequently accumulates in the lowest parts of the tubes, interfering with the traffic. Fig. 1840 shows the collector applied to the tube to remove this inconvenience. It consists of a small chamber fastened to the tube in such a way as not to interfere with the passage of the train; the water passes through the opening P, and when the chamber is full it can be emptied by removing the plug Q. These collectors are placed in convenient places along the line, where they are easily accessible. The pistons, Figs. 1841, 1842, are formed of a thin iron plate wrapped around a wooden cone, through which passes a rod with a screw thread cut at one end, this receives a nut to hold the plate that keeps the leather, which is notched around its edge, in position. The weight of the piston complete is 12·8 oz.

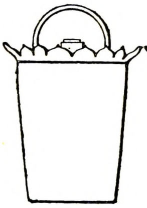
1839.



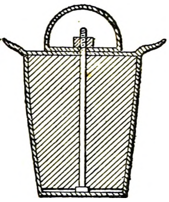
1840.

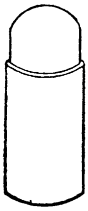


1841.

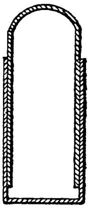


1842.





18·3.



1844.

The carriers employed to hold the despatches, Figs. 1843, 1844, are cylindrical, the outer sheath is made of leather, and the inner of sheet iron. Each carrier can hold from thirty to thirty-five despatches. It is found that the combination of leather and iron quite protects the contents from dampness and impurities in the tube, and the leather envelope will run for about 1200 miles before it has to be thrown aside. The iron portion lasts for an indefinite period. The weight of each portion is, for the leather, 2·3 oz.; for the iron, 6·4 oz.; and the carrier complete, and charged with thirty-five letters, weighs 12·5 oz.

The following is a list of dimensions of the tubes, pistions and carriers employed;—

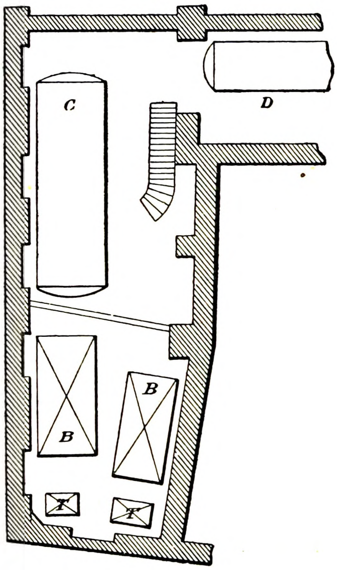
			inches.
Tubes	Straight	Standard diameter inside	2·559
		Minimum ,, ,,	2·5197
	Curved	Standard ,, ,,	2·559
		Minimum ,, ,,	2·441
	Pistons	Diameter of head	2·362
		Length ,, ,,	3·543
	Carriers	Outside diameter	2·283
		Length	5·118

In Figs. 1845, 1846 are shown the arrangement of the two stories of a typical station; the reservoir C, pumps B B, turbines T T, and other accessories being on the lower floor, and the offices O, receiving and transmitting apparatus F F, and messengers' room M, above. In some cases the cellars are made use of to receive the reservoirs, the water being brought in from the street main, or, if necessary, cellars separated from the station building are employed.

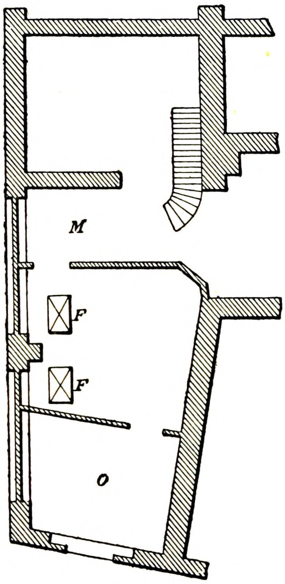
Two classes of receiving and transmitting apparatus are employed in the stations, vertical and horizontal, the latter being preferable if space permits of its installation. The vertical arrangement is shown in Fig. 1847. The tube A is a vertical extension of the pneumatic pipe T. The door P, placed at the bottom of the tube A, serves to introduce or remove the carriers and piston. The two cocks, R and R', controlled by the handle *m*, are arranged so that when one is shut the other is opened. These establish communications either with the atmosphere or with the compressed-air reservoir, according to whether the apparatus is receiving or transmitting despatches. In the former case the cock R is closed, and R' is opened, and the air in advance of the train escapes, the train rises into the tube A, strikes against the top, and then descends until it is arrested by the fork F, placed in the open door P. The cases are then removed and placed in a basket C for distribution. If, on the other hand, a train has to be transmitted, the carriers and pistons are placed in the tube through the door P, which is then closed; the cock R is opened and R' shut, and the compressed air from the reservoir propels the train to its destination.

The horizontal apparatus consists of a conical box mounted on cast-iron brackets. The carriers travel from the tube into the former, and are removed by operating a lever, which releases the hinged lid covering the upper part of the box. In transmitting, the carriers are inserted in the tube through the door, which is then closed. A cock at the end of the apparatus places the box and tube in connection with the pressure or vacuum reservoir. In the forward part of the apparatus is a valve, operated by a handwheel. This valve is used to close the line for different requirements of service. Special receiving and transmitting apparatus are used at intermediate stations where no compressing machinery exists. Thus, suppose there exist three stations, A, B, C, of which B possesses no motive power. It is necessary, therefore, to depend upon the power at one of the terminal stations for the transmission. In working, the carriers at B must be removed and

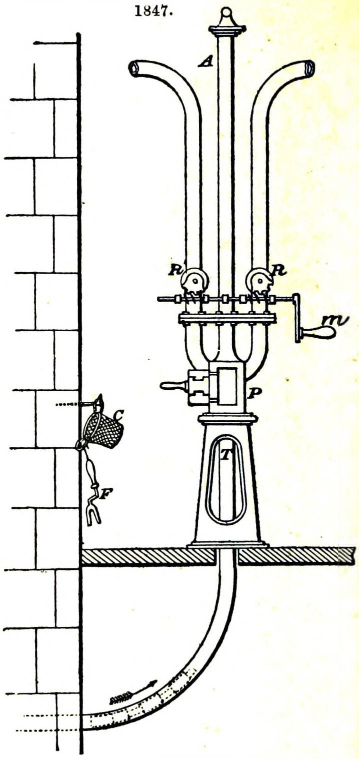
1845.



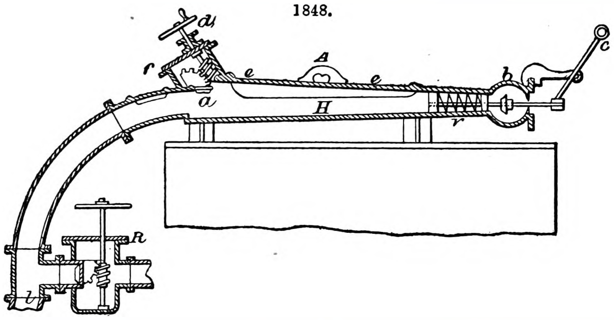
1846.

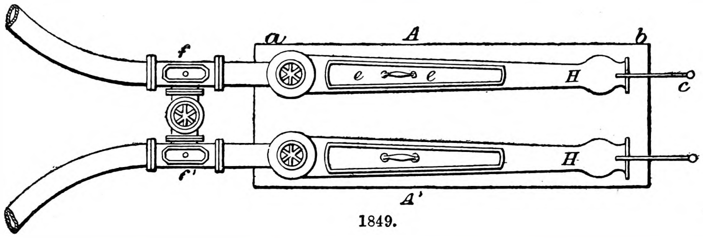


1847.



1848.



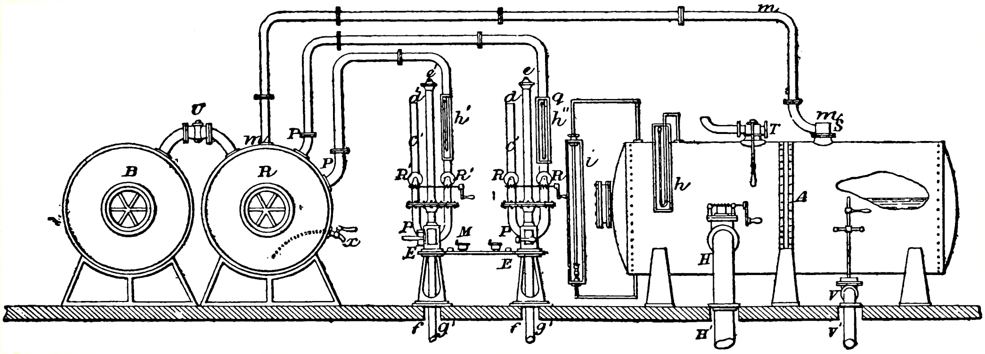


1849.

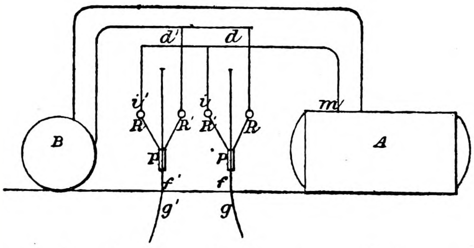
replaced by others, and the new train forwarded to A or C, according to circumstances. The apparatus employed for this purpose is shown in Figs. 1848, 1849. When the train is forwarded to A, the air in front escapes through the opening *c*, the valve *b* being open as well as the valve *a*. The train having entered H, it pushes the spring *r*, and closes the valve *b*, which is held in its new position by the counter-weight *c*. The screw *d* is then moved, so as to close the tube *l*. The cover A of the box may then be raised, and the train removed without loss of air pressure. This being done, the door *f*, Fig. 1849, is opened, the carriers and piston of the new train introduced, the compressed air is transferred to the new line by the valve R, and the train is then transmitted to station C.

Fig. 1850 is one of the means employed for producing a vacuum or compression to work the tubes. In producing compressed air, the water is admitted into the reservoir A, and forces the air contained in it into the receivers B R, each of about 215 cubic feet capacity. The apparatus is placed on the ground-floor of the station; and between the orifice V′ of the discharge pipe V V′ and the point where the water is discharged, there is a difference of level ranging between 13 ft. and 26 ft. The pipe V′ ends in a receiver in the sewer. With a difference of level of 16 ft. or 17 ft., the power at command in the reservoir will be about half an atmosphere; and when placed in connection with the tube, the train of carriers will be put in motion by the difference of pressure due to the atmosphere on one side, and the partial vacuum on the other. The ordinary dimensions of the receiver A, and the head of water ranging from 13 ft. to 26 ft., are sufficient to give a normal speed of from 1300 ft. to 2000 ft. a minute; and this duty may be increased by taking away a further quantity of air in the reservoir with the escaping water. The supply pipe for filling the reservoir from the water main is shown at H; B R are the compressed-air chambers, and U is a cock for regulating the communication between them. E E′ are the vertical receiving and distributing apparatus; R′ R′ are pressure and exhaust valves; M is an electric bell, and S is a check valve; *e e′* are the receiving columns; *f g* are the pneumatic tubes; *m m* is the pipe communicating between the reservoir A and the receiver B; *g p* are the pipes leading from the receivers to the reception apparatus. A modification in this arrangement is shown in Fig. 1851, where the exhaust pipes are connected by a pipe *d m*, and extended to the reservoir A. The cocks R and R′ are not coupled, but are worked independently, R for transmission under pressure, R′ for reception by vacuum. In this arrangement, when the apparatus is employed for reception by compressed air from the adjacent station, the air is exhausted by one of the openings P P. Fig. 1852 represents a vertical apparatus, in which, by means of the pipe *x*, closed by the cock R″, the air in advance of the train can be liberated into an underground cellar.

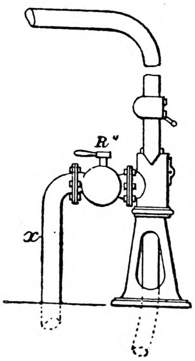
1850.



1851.

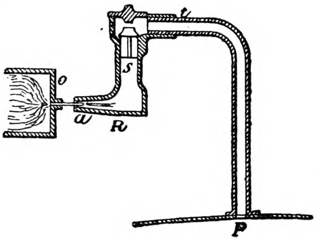


1852.



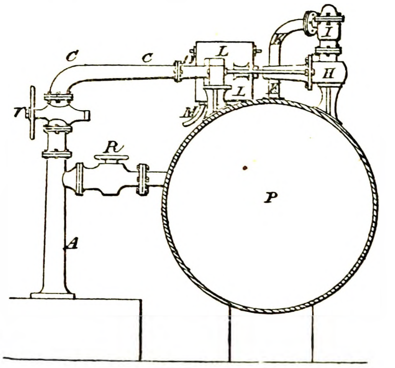
Considerable economy in working has been effected by employing a jet to draw in air for working with compression. Fig. 1853 is the arrangement, in which P is a reservoir of 282·5 cubic feet capacity. The water arriving by the city main passes through the opening O into the apparatus R. This apparatus is provided with a valve S, for preventing the escape of the compressed air in the reservoir P. With a head of water of 28 ft., a quantity of air equal to 0·465 of the volume of water may be drawn into the reservoir; and the final pressure of air obtained was 1·21 inch of mercury. This system possesses great advantages. By simple displacement, a volume of air at atmospheric pressure, equal to the volume of water removed, is obtained; but by the addition of the induced current arrangement, a volume

1853.

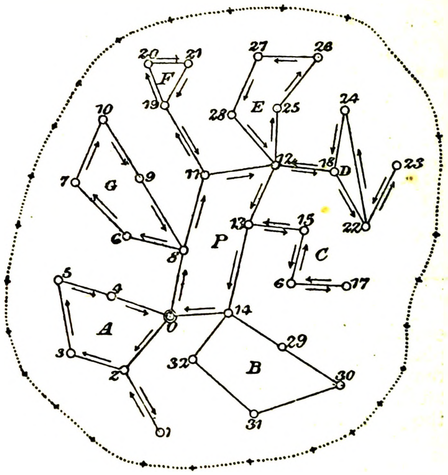


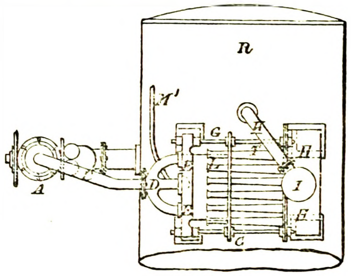
equal to 1·465 results, representing an economy of about 32 per cent. Figs. 1854, 1855 show the complete arrangement as designed for a station. The compressed-air reservoir is at P, and it may be fed by the direct introduction of water from the hydrant A by means of the cock R. When the injector is used R is closed, and the valve *r* is opened. The water then passes by the tube C C D into the box E, and the water is discharged into the tubes T. In Fig. 1855 six of these tubes are shown to represent the proportion necessary between the amount of discharge and the size of the receiver P. The box E is connected to the box H by the bars G G, the box H receiving the water and the induced air which pass through the valve box I and pipe K into P. By means of the bar G G the position of the box E, with reference to the mouthpiece T T, may be regulated, so as to obtain the best result. As well as the modes already indicated, the water has also been utilized by means of turbines used to drive double-acting pumps for compressing or exhausting the air. With a fall of 39 ft. 6 in., the turbines employed, which are 23 in. diameter, make 245 revolutions a minute, and discharge 1·72 cubic foot a second when the maximum number of ten openings are supplied. The speed of 245 revolutions is brought down to 22 at the pumps. In the plans of the station, Figs. 1845, 1846, this arrangement is shown, and may here be again referred to. The basement contains the turbines T, and the pressure and vacuum reservoirs C and D. The water pressure throughout Paris is of course unequal, and at some high stations steam power is resorted to of necessity.

1854.



1856.



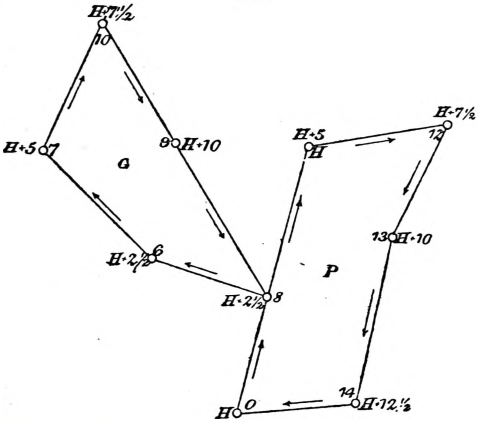


1855.

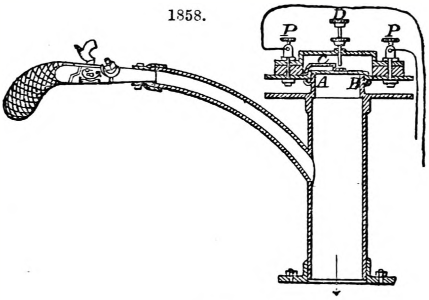
The practical working of the pneumatic system of Paris may now be briefly considered. The carriers forming the train are made up, addressed labels being affixed to the carriers destined for each office, and circulation commences in full activity at 8 A.M. Fig. 1856 is a diagram of the system, the arrows indicating the directions of the traffic. On the close polygons of the circuit, the trains are worked alternately in each direction for three months, to remove any obstruction which might otherwise accumulate. In winter the trains are more soiled that in summer; the air from the station being heated, deposits the vapour with which it is saturated in the tubes. This inconvenience is partly removed by establishing the air reservoirs in cellars where the temperature is low. A train on being sent from O arrives at station 8 with the forward carrier filled with despatches for 8 and its district, the remaining carriers being for stations 6, 7, 10, 9. The first carrier is removed, and another takes its place, containing the despatches collected at station 8 or 6, 7, 10, 9, which the previous train from circuit G has brought there. The newly made-up train is then forwarded on the 8–11 line, and so on round the circle back to O, the operation described being repeated at the stations 11, 12, 13, 14. The train service is controlled by means of the official instructions relating to the actual times of arrival and departure. This time-table, and a plan of the circuit, to which the station belongs, as in Fig. 1857, is hung on the wall of the office. Only the times of departure are given, the periods of arrival being deduced. By the formula $H + C$, where H is the time of departure from the central bureau O, and x a constant time for each station, the moment at which any train, the number of which is known, will pass, is easily ascertained. Exact accord of time between the stations is necessary, and electric communication is established over the whole system. Returning to Fig. 1856, at station 11, it will be seen that three circuits, P, E, D, centre at this point, which is consequently of high importance. Three trains, from 11–12, 23–12, and 18–12, are received and transferred here in the manner already described. To take an example, a despatch left at station 10, at 9h. 35m. A.M., to be delivered in the district served by station 18, is sent on by a train leaving O at 9h. 30m., and quitting station 10 at 9h. 37m. The omnibus carrier of circuit G leaves it at station 8 at 9h. 41·5m. The message is then transferred to the omnibus carrier of circuit P, and reaches station 12 at 9h. 51·5m. There it is placed in the similiar carrier of circuit D, and reaches station 18 at 9h. 54m. Delivery of the despatch is made fifteen minutes later.

Intimately connected with the working of the tubes is the removal of obstructions which occur from time to time, causing not unfrequently serious inconvenience and delay. The most general cause of obstruction is a stoppage of the train arising from accident to the tube, to the carriers or piston, or to the transmitting apparatus. In such cases the delay is generally very brief, it being for the most part sufficient to reverse the pressure on the train from the next station, and to drive it back to the point it started from. If one or more of the carriers break in the tube, reverse pressure is also generally sufficient to remove the obstacle; but where this fails, the point of obstruction must be ascertained. This is done by carefully observing the variations of air pressure in the reservoir, when placed in connection, first with a line of known length, and then with the obstructed tube. By this means the position of the obstruction can be ascertained within 100 feet. Or the tube may be probed with a long rod up to a length of 200 feet. A very ingenious apparatus by Ch. Bontemps, Fig. 1858, is employed to ascertain the exact position of the obstruction. It acts by the reflection of sound waves on a rubber diaphragm. A small metal disc is cemented to the rubber, and above this is a pointed screw D. An electric circuit is closed where the points C and D are brought in contact. To locate an obstruction a pistol is fired into the tube as shown, and the resulting wave traversing the tube at the rate of 330 metres a second strikes the obstruction, and is then reflected against the diaphragm, which in its turn reflects it to the obstacle, whence it returns to the diaphragm. By this means indications are marked on the recording cylinder, and if the interval of time between the first and second indications be recorded, the distance of the obstacle from the membrane is easily ascertained. The chronograph employed is provided with three points; the first of these is placed in a circuit, which is closed by the successive vibrations of the diaphragm; the second corresponds to an electric regulator, marking seconds on the cylinder; and the third subdivides the seconds there marked. Fig. 1859 indicates a record thus made. In this case the obstacle is situated at a distance of 62 metres, and the vibration marks thirty-three oscillations a second. The interval occupied by two successive marks from the diaphragm on the paper, corresponds to twelve oscillations, and the distance of the obstruction is then calculated by the following formula;—

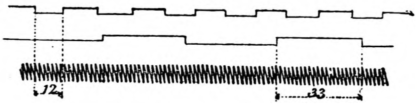
1857.



1858.



1859.



$$D = \cdot 5 \times 330 \times \frac{12}{33} = 60 \text{ metres};$$

so that the distance of the obstacle is recorded within 2 metres.

Amongst the special causes of accident may be mentioned, the accidental absence of a piston to the train, breaking of the piston, and the freezing up of a piston in the tube.

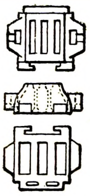
PUMP.

Blake's steam pump possesses several novel features, the leading one being a combination of two slide valves which render the action of the pump positive and continuous under any pressure, and working at any rate of speed, fast or slow.

Fig. 1864 is a longitudinal section of the Blake pump, as made by S. Owens and Co., London, Fig. 1862 being a section and plan of a secondary cylinder which contains an auxiliary piston for actuating the main valve, whilst Fig. 1863 is a half-end elevation and cross-section of this cylinder. Fig. 1860 is a plan, elevation, underside view, and the upper part of Fig. 1861 an end elevation of the auxiliary valve; the two lowest sections in Fig. 1861 being sections of the main valve. Both the main and auxiliary valves are plain flat slides, the main valve being a common D valve and the auxiliary a valve of the form shown. The latter, being attached to a rod which receives an impulse from the main steam piston, is moved with the same absolute certainty as is the slide valve of an ordinary engine driven by an eccentric. The secondary cylinder is mounted on the primary or main cylinder. The ordinary spring-ring steam piston, which it contains, drives the main slide valve which works on the upper face of the auxiliary valve. This valve has three ports of equal area, which correspond in every position with the ports of the main cylinder.

In working, if the main piston should attain a velocity in excess of the piston which actuates the main valve, the piston strikes the tappet, Fig. 1864, projecting through the cover into the main cylinder. By this means a lead is given to the main valve, steam being thereby admitted in front of the piston forming a cushion, and giving steam to start the piston on its return stroke. It will be observed that the auxiliary valve has two slots cut in its underside as in Fig. 1860. These slots communicate with the main exhaust passage, and also give steam from the valve chest to both ends of the auxiliary, or main valve piston, alternately. The result of this is, that directly the auxiliary valve is thrown over by the action of the tappet rod, steam is given on one side of the auxiliary piston, and exhaust takes place on the other. On the opposite side of the auxiliary valve, the upper side in Fig. 1860, another slot is formed, which at the right moment enables a small quantity of steam to pass to the exhaust side of the auxiliary piston, and so to form a cushion to prevent it striking the cylinder cover. In these combined operations no waste of steam occurs, as it is retained, and gives out its useful effect on the return stroke.

1860.



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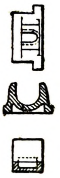
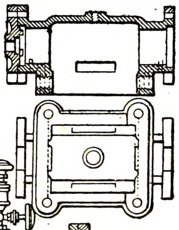
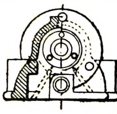
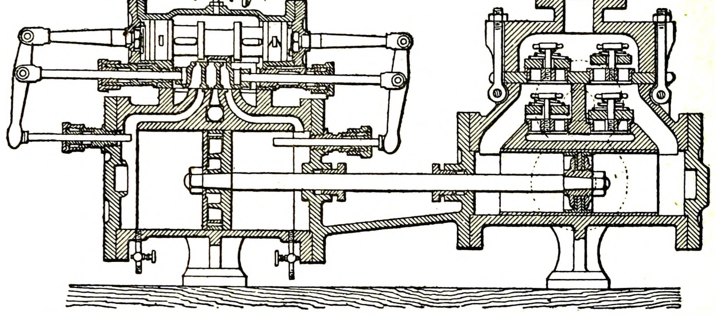


1862.



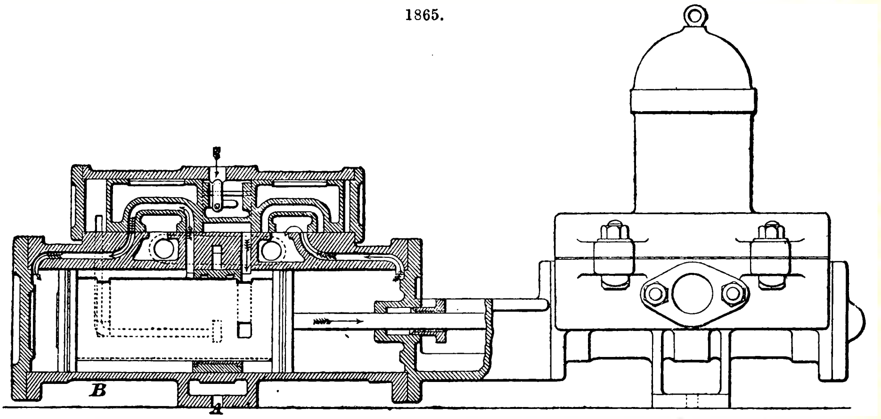
1863.





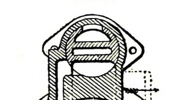
1864.

1865.

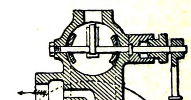


The result of this ingenious combination of valves is a perfectly continuous action without dead point, and unassisted by extraneous means. This is attained without any complex internal arrangement, and without the presence of parts which are liable to get out of order. Of the excellent working of the Blake pump at extreme ranges of speeds, the following experiments are a proof. A 5-in. pump with an 8-in. steam cylinder having a 12-in. stroke was started to work at 155 single strokes a minute, and the speed was varied down to 25 strokes. It was then again run up to a high speed and suddenly set, with the delivery throttled to represent a head pressure of water of 230 ft., and with an average steam pressure of 40 lb. to run at the rate of one stroke in twelve minutes or five strokes an hour, delivering water throughout. We thus have a piston speed of 1 in. a minute or 5 ft. an hour, and a continuous delivery of water.

1866.



1867.



It is needless to observe that such a slow speed as this could not possibly be required in practice, but it illustrates the reliability of the pump either in quick or slow working.

The principal details of the steam pump devised by W. Walker, and made by Clayton, Son, and Howlett, of London, are indicated in Figs. 1865 to 1867. Fig. 1865 is a side elevation of the pump with the steam cylinder in section; Fig. 1867 being a transverse section through the centre of the cylinder at A; and Fig. 1866 a similar section through the end at B. Although, from the description, the pump appears somewhat complex, it is not really so, there being but two moving parts, if we except the pump valves.

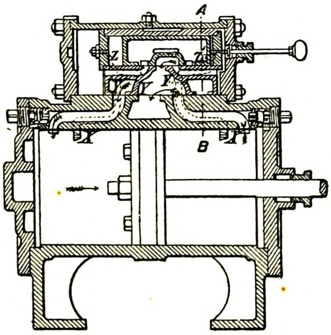
The piston is formed with two heads connected together by a barrel, the heads being packed and fitting the interior of the steam cylinder. At about the centre of the length of the cylinder is an annular partition in which the barrel slides steam tight. A key fixed in the partition and entering a groove formed in the barrel prevents it from rotating. The steam cylinder is formed with a chamber above it, which receives the slide valve. The valve consists of two parts, which are connected together by a link. The two sections of the valve are formed with passages, which serve to establish communications for the flow of steam, from the annular spaces between the piston barrel and the cylinder to the ends of the cylinder. The valve has recesses which at the proper time establish communications with the exhaust passages. The valve is not required to be quite steam-tight within the chamber, and therefore is not packed. Steam is admitted to the central space between the two sections of the valve through an opening at the top, as indicated by the arrow, and part of the steam finds its way by leakage into the end spaces of the valve chamber. A passage formed in the cylinder casting extends from the left end space of the valve chamber, to a port formed in the central partition, as represented by the dotted lines in Fig. 1865. A similar passage extends from the right end space to a second port formed in the partition, but as the passage is formed in the part which is cut away in Fig. 1865, it does not appear there.

Two passages are formed in the barrel, in such a manner and in such positions as that, when the piston approaches the termination of its stroke in either direction, one of these passages will connect either of the passages seen on the left and right hand of the barrel in Fig. 1867, with an upper passage which extends into the exhaust. The effect is, that steam will flow from either of the spaces at the ends of the valve chamber into the exhaust, and the equilibrium of pressure upon the ends of the valve thus being disturbed, the valve will be moved in the direction towards the space which has been so exhausted. Supposing the parts to be in the positions, Figs. 1865 to 1867, high-pressure steam would be passing through the port to the right of the central annular partition, into the annular space at the fore end of the piston, and at the same time the steam, which had acted during the immediately previous stroke, would be passing through the port and passages to the left of the annular partition into the space next the cylinder cover in which the steam would expand, and the piston would, therefore, be propelled in the direction indicated by the arrows in Fig. 1865, the exhaust steam flowing from the front end of the cylinder into the exhaust passage. The movement of the piston in this direction would continue until the piston had moved into position to connect the left-hand and upper passages, Fig. 1867, when steam would pass from the left-hand space in the valve chamber into the exhaust passage, and the excess of pressure within the space at the other end of the chamber, would force the valve towards the opposite end.

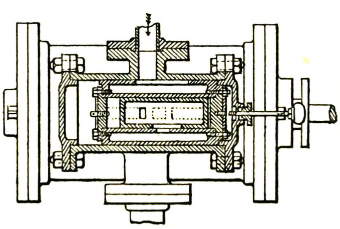
The effect of this movement of the valve would be to open the port on the left of the annular partition for the admission of high-pressure steam into the annular space on the same side, and to establish a thoroughfare for the flow of expanding steam, from the annular space on the other side through the passages above it into the space in front of the cylinder, the passage near the cylinder cover being made to communicate with the exhaust passage, whereby the reversal of the direction of motion of the piston is effected. A starting handle is provided in order that the valve may be worked by hand when the pump is to be set in motion after being at rest. The handle is mounted on a rocking shaft on which a lever is fixed which gives motion to the valve when the shaft is rocked by means of the handle. The pump itself possesses no special features, being of the ordinary form.

These steam pumps, it is stated, effect a very marked economy of fuel. They work high and low pressure expansively, and will deliver a constant stream of water at any ordinary height.

1868.

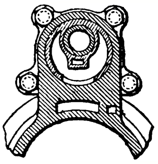


1869.

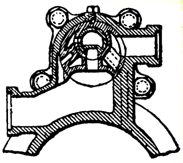


Figs. 1868 to 1871 are of one of Hayward Tyler and Co.'s "Universal" steam pumps, with the slide valve arranged on the outside of the cylinder. Fig. 1868 is a vertical longitudinal section through the cylinder and valve chest; Fig. 1869 a horizontal longitudinal section through the valve chest; and Fig. 1870 a cross-section through A B, Fig. 1868. Fig. 1871 is also a cross-section of the valve chest taken through the centre of the exhaust port. When the main piston passes over the ports X X′ in the cylinder, steam is admitted to the ports Y Y′ in the main slide, which ports again communicate with the small slide through the ports Z Z′ to either end, as the case may be. The small slide is then moved over, and supplies steam to the alternate ends of the main slide, and the ports Y Y′ are placed in proper position for the return stroke; when the movement is reversed the same process is enacted, the ports X Y Z or X′ Y′ Z′ come into use alternately, as the piston passes to the ends of the cylinder. The exhaust of the small slide is effected in a similar manner, by its ports coming into alignment with a port in the main exhaust port. This pump works well, and reverses slowly at the end of its stroke, allowing time for the valves to fall. It also enables a given length of steam cylinder to accommodate a longer stroke than is possible with the ordinary arrangement, and some, in addition, enable the valve to be worked by hand if required; this is at times a convenience.

1870.



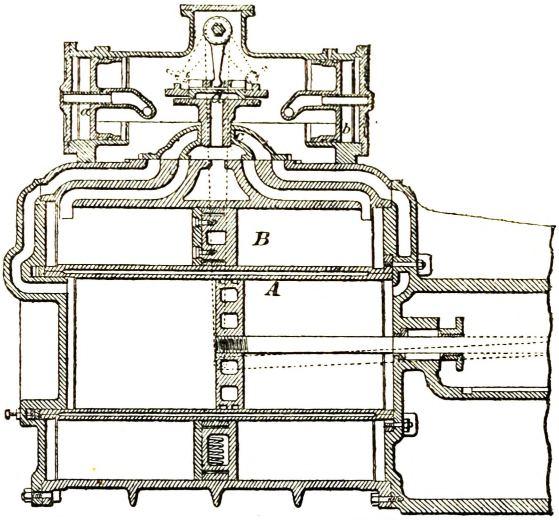
1871.



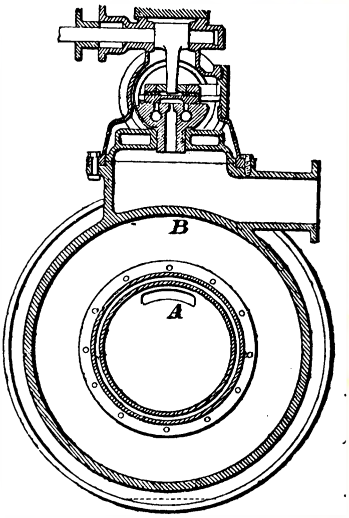
Figs. 1872 to 1874 are sections of the steam cylinders of Cherry's compound steam-pump, made by Tangye Brothers, Birmingham. The low-pressure cylinder B surrounds the high-pressure cylinder A, the low-pressure piston being annular, and having two piston rods which are attached to the same crosshead as the rod of the high-pressure cylinder, which is fitted with a liner, the space between this liner and the cylinder forming a steam jacket from which heat is radiated into both cylinders.

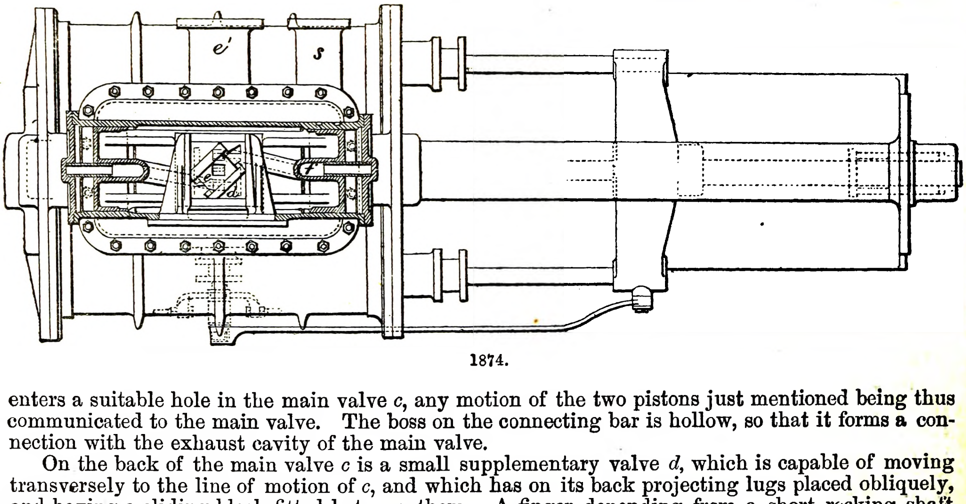
The distribution of steam to both cylinders is effected by a single slide valve *c*, the passages for the high-pressure cylinder being formed in the cylinder covers. At the ends of the valve chest are short cylinders *a* and *b*, containing pistons which are both cast in one piece with a connecting bar having steam passages formed in it. From this bar a cylindrical boss projects downwards, and enters a suitable hole in the main valve *c*, any motion of the two pistons just mentioned being thus communicated to the main valve. The boss on the connecting bar is hollow, so that it forms a connection with the exhaust cavity of the main valve.

1872.



1873.





1874.

On the back of the main valve *c* is a small supplementary valve *d*, which is capable of moving transversely to the line of motion of *c*, and which has on its back projecting lugs placed obliquely, and having a sliding block fitted between them. A finger depending from a short rocking shaft takes hold of this sliding block. The rocking shaft passes out through a stuffing box at the side of the valve chest, Fig. 1873. Outside the valve chest the rocking shaft carries a forked arm having adjustable contact pieces, which, at the ends of the stroke of the main pistons, are struck by a pendulum lever connected by a link with the main crosshead, shown by dotted lines in Figs. 1872, 1874.

When the main pistons are approaching one end of their stroke, for instance, that to the left hand of Fig. 1872, then the pendulum lever strikes one of the contact pieces on the forked arm carried by the rocking shaft, and partially rotates that shaft. This movement shifts the sliding block on the back of the small auxiliary slide valve, and causes the valve to move transversely, thus uncovering one of the auxiliary steam ports, Fig. 1873, and admitting steam to the short cylinder *a* at the end of the valve chest. This admission of steam shifts the main valve towards the right, and thus admits live steam to the left-hand end of the high-pressure cylinder, at the same time placing the left-hand end of the low-pressure cylinder, and right-hand end of the high-pressure cylinder, in communication. The main pistons then commence their stroke towards the right. In addition to the transverse movement of the auxiliary valve admitting steam to *a*, for the purpose of shifting the main slide valve, immediately that valve begins to move it would, through the effect of the inclined slides at the back of the auxiliary valve, shift that valve so as to cut off steam from the auxiliary cylinder *a*. The effect of this is that the quantity of steam admitted to the auxiliary cylinder at each stroke is only that sufficient to start the main valve, the remaining movement of that valve being effected by the expansion of the steam in the auxiliary cylinder. Referring to Fig. 1874, it will be seen that a simple arrangement is provided for cushioning the auxiliary pistons. This consists of a tube in each auxiliary cylinder, which fits and slides in the corresponding steam passage leading to that cylinder, this tube being perforated so that the steam can pass out from its interior into the cylinder. The movement of the corresponding piston covers the perforations in the tube, before the end of the stroke is reached, and thus shuts sufficient steam into the cylinder to form a cushion.

A steam pump, Figs. 1875, 1876, by Hayward Tyler and Co., of London, has the compound system, and the valve gear, invented by Cope and Maxwell, acts upon the principle of controlling the rate of movement of the engine to which it is applied, by the flow of a liquid from one end to the other of a cataract cylinder.

From Figs. 1875, 1876 it will be seen that the two steam cylinders and the pump cylinder are placed in a line, the high-pressure piston rod *a* and the two low-pressure piston rods *a′ a′* being connected to a crosshead, from which an arm *b* projects downwards, Fig. 1875. The lower end of this arm is coupled by a link *c* to the lower end of a lever *d*, carried on a rocking shaft *e*. This rocking shaft also carries a pair of arms *f*, which, by means of a pair of links *f′ f′*, are coupled at *g* to a pair of levers *i h* vibrating on a fixed centre at *h*. These levers are also connected at *g* by links *g′ g′* to the base-plate *l*, having cast in one piece with it the two cylinders *m n*. This bed-plate, with its cylinders, slides on suitable guides formed on the girder carrying the fixed centres *e* and *h*. This motion we will explain presently.

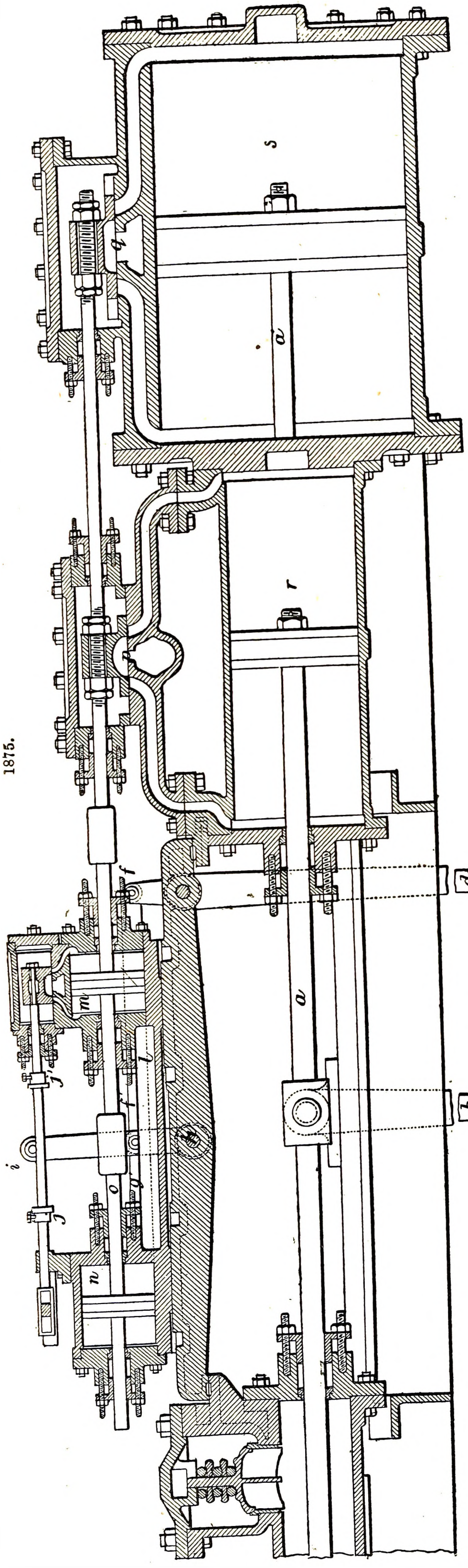
The levers *h i*, at their upper ends *i*, are capable of operating on striking pieces *j j′*, adjustable on the spindle of the slide valve *k* of the small steam cylinder *m*, the outer end of this spindle having formed in it a slot through which a hand lever passes. The second cylinder *n*, on the sliding bed-plate *l*, is a cataract cylinder, and its piston rod *o* is coupled to that of the cylinder *m*, and through the latter to the spindles of the slide valves *p* and *q* belonging to the main cylinder *r* and *s*. The cataract cylinder is filled with water or oil, and the flow of this liquid from one end to the other is controlled by the valve *v* fitted to the bye-pass channel, as shown in the sectional plan, Fig. 1876, which also shows how the steam is led to and from the valve chest of the small cylinder *m* by the sliding steam and exhaust pipes *t* and *u*, respectively communicating with the steam inlet and exhaust passages of the main high-pressure cylinder *r*.

When the parts are in the positions indicated in the figures, the slide valves are all at the middle points of their travel, and the steam is thus shut off from all the cylinders. If the engine is started by moving the slide valve of the small steam cylinder *m* towards the left, so as to admit steam to the right-hand end of the cylinder *m*, the effect of this will be to cause the pistons of the cylinders *m* and *n* to move towards the left, at a rate controlled by the adjustment of the valve *v* in the bye-pass of the cataract cylinder *n*.

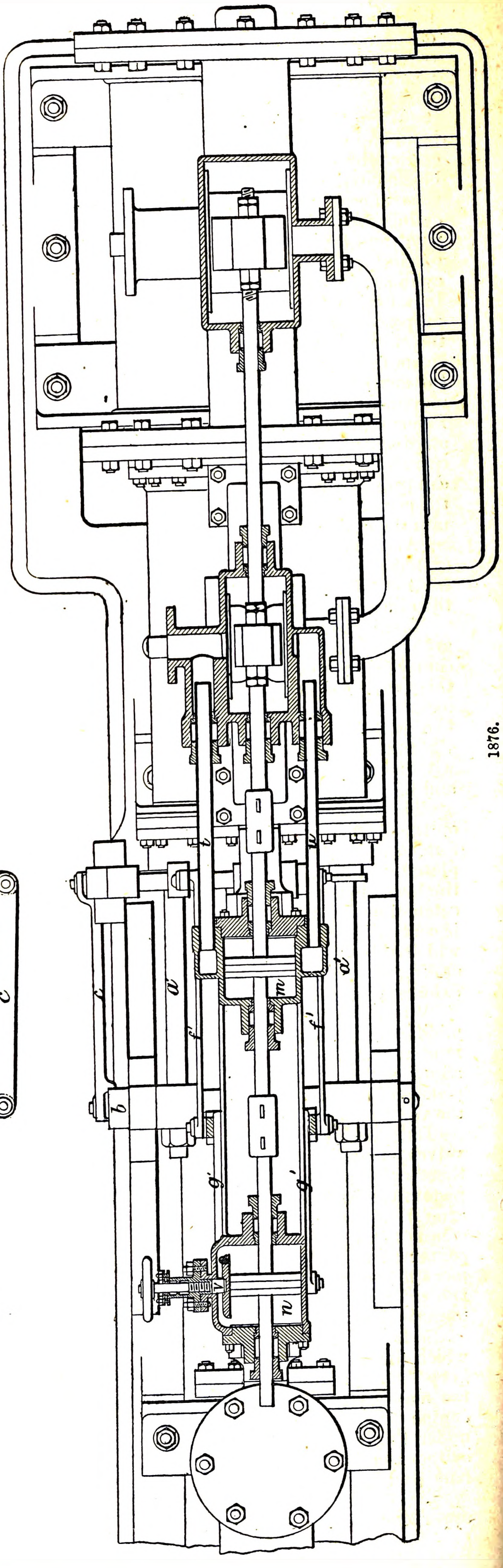
But the movement of the pistons in the cylinders *m* and *n*, also causes the movement of the slide valves *p* and *q* of the main cylinders *r* and *s*, and thus admits steam into the right-hand ends of these cylinders, causing their pistons to move to the left. Again, this movement of the main pistons carries the arm *b* to the left also, and through the intervention of the link *c*, lever *d*, and arms *f*, shifts towards the right the sliding bed-plate *l* with its cylinders *m* and *n*. But the cataract cylinder *n*, in being thus moved towards the right also carries with it its piston, which is connected to the valve spindles of the main slide valves *p* and *q*, and we thus see that the movement actually imparted to these valves must be equal to the difference between the movement of the cataract piston towards the left in its cylinder, and the movement of that cylinder itself towards the right.

So long as the main pistons do not tend to make a stroke at a higher rate of speed than that for which the cataract is set, so long will the movement of the cataract piston in its cylinder suffice to keep the main slide valves shifted towards the left, thus admitting steam to the right-hand end of the main cylinders, and causing the main pistons to move towards the left. If, however, the engine moves too fast, then the movement of the bed-plate *l* and cylinders *m n*, towards the right, under the action of the levers *d* and *f*, overpowers the movement of the cataract piston in its cylinder, and shifts the main slide valves towards the right, thus shutting off steam from the right-hand end of the main cylinders.

This continues until, as the main pistons approach the end of their stroke towards the left, the upper ends of the levers *h i* come into contact with the striking piece *j′*, and shift the small slide


s
q
a
r
f
d
c
b
m
l
j
i
o
g
n

1875.


t
u
c
a
a'
m
f'
b
g'
n

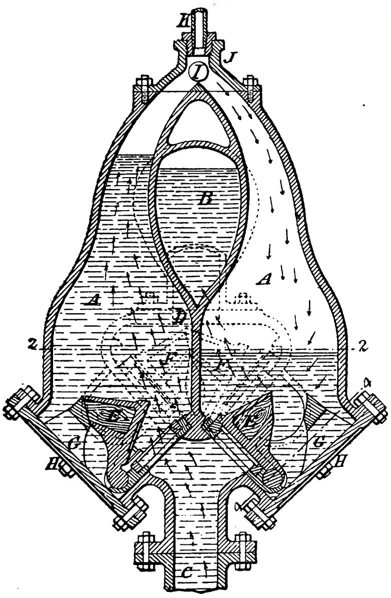
1876.

valve towards the right, thus reversing the admission of steam to the cylinder *m*, and causing it to enter the left-hand end of that cylinder. The effect of this is, that for a short period, the piston of the cylinder *m* as well as that cylinder itself, both move towards the right, and the main slide valves *p* and *q* are thus pushed over, reversing the admission of steam to the main cylinders. During the movement of the main pistons from left to right, the same action as that above described takes place, but the parts move in opposite directions.

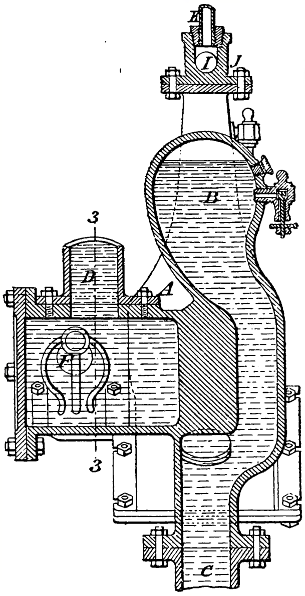
One effect of the action of this valve gear is to produce a pause at each end of the stroke of the main pistons, thus giving time for the pump valves to close properly. The compound pumping engine, Figs. 1875, 1876, has steam cylinders 12 in. and 24 in. in diameter with 30 in. stroke; the pump, which is double acting, having a cylinder 7 in. in diameter.

The pulsometer invented by Hall is a somewhat singular but simple direct acting steam pump. Figs. 1877 to 1879 illustrate one of the forms of this pump, made by the Pulsometer Engineering Company, London. The apparatus consists of two chambers, A A, which terminate at the top in tapering necks, leading to corresponding openings or passages in an upper casting J, to which the steam pipe K is also connected. This casting J contains a spherical valve, capable of closing the openings leading to either of the chambers A A. At the bottom of the chambers are inlet valves E E, covering openings communicating with the suction pipe C. Adjoining the chambers A A, and communicating with them by suitable passages, Figs. 1878, 1879, there is also a third chamber, fitted with the discharge valves F F. Between A A, and cast in one piece with them, is an air vessel B, which is connected only to the suction, but which in some of the pulsometers is divided by a partition, so as to form both suction and delivery air vessels. Near the top of each chamber A A are provided small air valves, opening inwards. Having charged the apparatus with water, and steam being turned on, the steam passing down the pipe K will enter one or the other of the chambers A A, according to the position which the small valve in the casting J happens at that moment to occupy, and pressing on the surface of the water in that chamber, will force it out through the discharge valve. During this process, owing partly to the shape of the chamber and the consequent steadiness of the water surface, the condensation of the steam will be small, but immediately the level of the water falls to that of the discharge passage, the steam rushes out through that passage, and in doing so disturbs the water, and causes it to be thrown up amongst the steam, thus inducing the rapid condensation of the latter. The effect of this is that a vacuum is suddenly formed in the chamber in which the steam has just been acting, and the water rushes in through the suction valves, the small ball valve at the top being at the same time drawn promptly over, thus shutting off any further supply of steam from the chamber which has been acting, and admitting steam to the other chamber, where the same series of operations is repeated. The small air inlet valve fitted to each chamber A, comes into action when the vacuum is formed within the chamber, and by partially destroying the vacuum, checks the rush of the water as the chamber fills, and thus prevents the ball valve at the top from being thrown off its seat by the impact of the water,

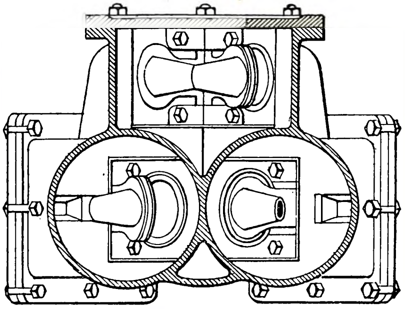
1877.



1878.



1879.



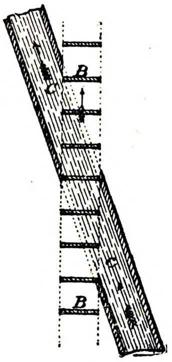
as might otherwise occur. The air, by preventing the intimate contact of the steam and water, also seems to check the condensation of the former. The valves used in the pulsometer are worthy of notice; they are, as will be seen, clack valves, closing on wooden seats, and fitted with wooden striking blocks at the back. They are arranged so as to be very readily accessible.

We are not in possession of any precise data as to the steam consumption of the pulsometer, when doing a known amount of work, but it is stated that, although not pretending to any high degree of economy, yet the instrument can compare favourably, as regards steam consumption, with many steam pumps now in use. Apart from any such question, however, the handiness with which the pulsometer can be applied in many out-of-the-way situations, and the small attendance it requires, will commend it for use under a variety of circumstances.

A most ingenious form of centrifugal pump is the helical pump, invented by John Imray. It was thought that if it were possible to cause a series of blades B B, Fig. 1880, to move through a liquid contained in a canal C C, in a direction as nearly as possible coincident with that of the canal, a current would be set up and maintained in the liquid at a velocity very nearly equal to that of the blades. Obviously this arrangement in a straight canal is impossible, because the series of blades would have to be infinitely extended, and there would be no means of closing the liquid in at the points where the successive blades enter and leave the canal. It seemed possible, however, to apply this principle, by arranging the blades and bending the canal round the circumference of a circle, in which case, the canal being inclined to the plane of revolution of the blades, would necessarily be of helical form.

The construction and action of the helical pump may be illustrated by imagining that a large shallow nut is tapped with a screw thread, making only two complete turns in the length of the nut, the space between the threads being about eight times the thickness of the thread, as shown in the diagram, Fig. 1881; and the helical channel is extended tangentially outwards a certain distance at each end of the nut. A cylindrical recess is turned out of the interior of the nut in the centre, to the same depth as the thread, and leaving a portion of the thread on each side of it, as shown by the dotted rectangle, Fig. 1881; and into this space is introduced a simple paddle-wheel, with a boss on each side, filling up the aperture of the nut. This combination then accurately represents the helical pump; the head of the nut forms a channel of square section, with a tangential inlet on the one side of the nut, and a tangential outlet on the other side, the body of the channel being carried helically round, so as to present an oblique opening on each side of the wheel to the spaces between the blades. The channel being charged with water, and the wheel being caused to revolve, the water caught between the blades is carried round with them, and gradually shunted across their width by the inclination of the helical sides between which it revolves, as in Fig. 1885, which may be taken as a developed view of a portion of the circumference of the wheel, and of the helical passage to and from the wheel. The water thus becomes a current, entering by the one tangential passage and issuing by the other, with a velocity nearly equal to that of the wheel blades.

1880.



1881.

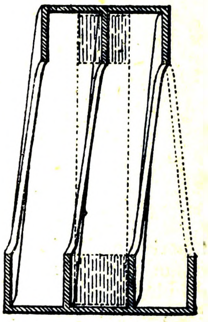


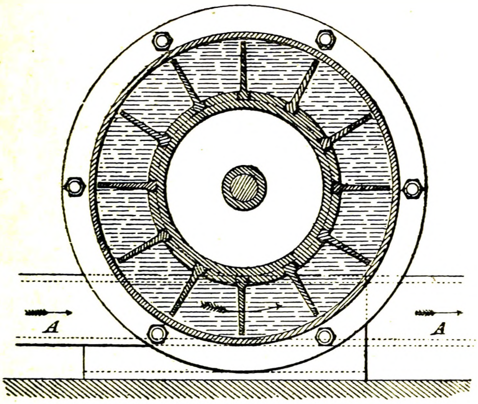
Fig. 1882 is a longitudinal section of the wheel and one-half of the casing; Fig. 1883 is a plan; Fig. 1885 a transverse section; Fig. 1884 is an edge view of the wheel. The casing is made in two halves, both to the same hand and cast of the same pattern, bolted together and enclosing the wheel between them. Each half has a tangential passage A, one of which serves for inlet and the other for outlet, the direction of current being determined by the direction in which the wheel is made to revolve; the canal, beginning from the inlet passage and terminating with the outlet, is carried round two complete screw turns, the helical partition which would separate the one turn from the other being omitted to give room for the wheel. It will be readily seen that the workmanship necessary to fit up such a pump is of the simplest and cheapest character. The casings have only to be bored out in the centre to provide bearings for the shaft, and faced on the flanges to make a tight joint when they are bolted together; and for the wheel it is only necessary to bore out the boss and key it on the shaft. The bosses of the pump casing in which the shaft works require no glands, because owing to the centrifugal action there is always a suck in. Practically these bearings are lubricated with melted grease, which is drawn in very freely while the wheel revolves, and which, setting when the pump stops, effectually seals the bearings against leakage.

The blades usually employed are bent a little forwards at the entering edge, and backwards at the leaving edge, as at D D in Fig. 1884, rather for the purpose of stiffening them by the corrugation than for accommodating them to the flow of the water.

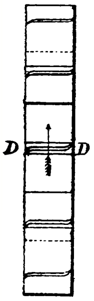
Some experiments were made with this pump to ascertain the efficiency in respect to the power expended in working it. The result of these gave as the work done 58 per cent. of the power applied, 42 per cent. of the driving power being lost in friction or otherwise. When the engine and pump were worked without water at the same speed, the friction was found to be about 14 per cent. of the total power which had been applied to pumping. As this was the friction while no work was done, and consequently while there was little strain on the moving parts, it might probably not be incorrect to assume that the total friction of the engine and pump while doing work must have been nearly double, or at least 25 per cent. of the total power developed; adding this estimate to the 58 per cent. of actual efficiency observed, the total 83 per cent, corresponds very nearly with the efficiency observed when speed only, without regard to power, was taken into account.

These results may be thus summarized. Assuming that the pump has such an area of passage and is driven at such velocity that it should, if there were no loss, deliver 100 gal., then it will actually discharge 82 to 85 gal., giving a slip equivalent to from 15 to 18 gal. Assuming that 100 ft. lb. are applied to drive the pump, then the actual work performed by it, that is to say, the weight of water multiplied by the height to which it is raised, will amount to about 58 ft. lb., the friction of the engine and pump being about 25 ft. lb., and the loss by slip being about 17 ft. lb.

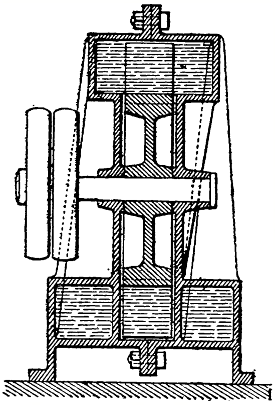
1882.

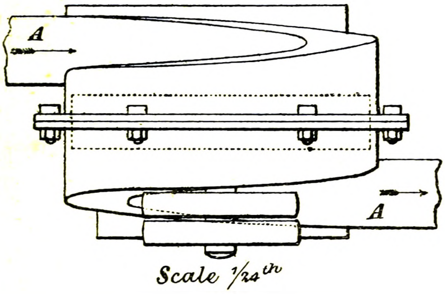


1884.



1885.





1883.

Figs. 1886 to 1889 are respectively a plan and section of the wells and pumps designed and erected by J. and G. Rennie, for rapidly emptying the dry docks at Chatham.

The following conditions were required to be fulfilled in the design for the pumps. They were to be capable of removing the water from two docks simultaneously in four hours, pumping into the basin and without discharging into the river, the water in the docks and basin standing at 27 ft. above the sills of the dock entrances at the commencement of the pumping. The pumps were also required to raise water from one foot below the bottom of the dock culvert, and discharge into the basin, or to pump from the river into the basin direct, in order to raise the level of the water in the basin when wanted. It was in addition considered desirable that in emptying the docks the water should be lowered as rapidly as possible to the level of the broad altar course, indicated by dotted line E, Fig. 1886, this depth being 15 ft. below the top, or 27-ft. water level, and estimated to contain about 18,000 tons of water. The remaining depth from this point to the floor or bottom of the dock is 15½ ft., containing about 12,000 tons of water; so that the total quantity of water to be pumped out in four hours was 60,000 tons, the lift increasing from zero to 30½ ft.

These requirements have been met by having recourse to dividing the lift for the lower portion into two parts, by placing the two pumps at different levels, each pump lifting the water through only half the total height, so that neither of them has to discharge against a greater head of water than about 15 ft.

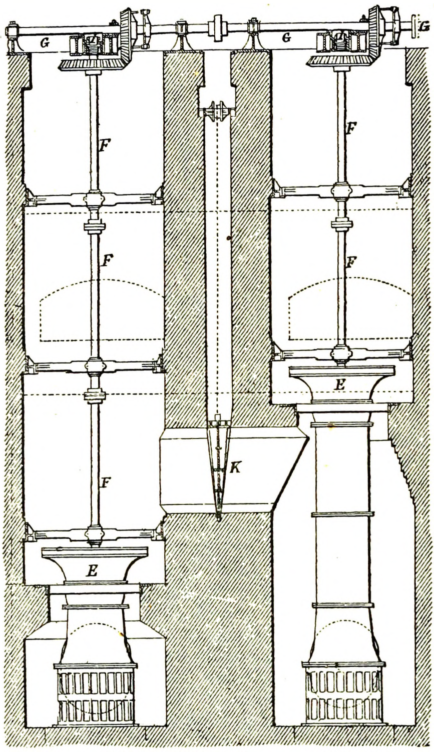
This arrangement renders it necessary for each pump to be placed in a separate well, with separate suction and discharge culverts, but with a communication between the two wells, above the discharge of the lower pump into the suction of the upper pump; and with the means of opening or closing this communication at pleasure by a sluice or penstock. The culvert C from the docks to the pump suction is 7 ft. diameter, and about 1050 ft. length, dividing just outside the pumping engine-house into two culverts A A, each 7 ft. high by 3 ft. wide; a sluice is fixed in the main culvert at the junction, as well as an independent sluice in each branch culvert. The pump-wells are 11½ ft. diameter, with a total depth of 55½ ft., and are constructed in brick, with granite copings and foundations.

The centrifugal pumps and wells are shown in the section and plan, Figs. 1886, 1887. The pumps E E work horizontally upon vertical shafts F, which have bevel wheels 5 ft. 8 in. diameter, fixed on their upper ends, driven by 6-ft. wheels upon a horizontal shaft G.

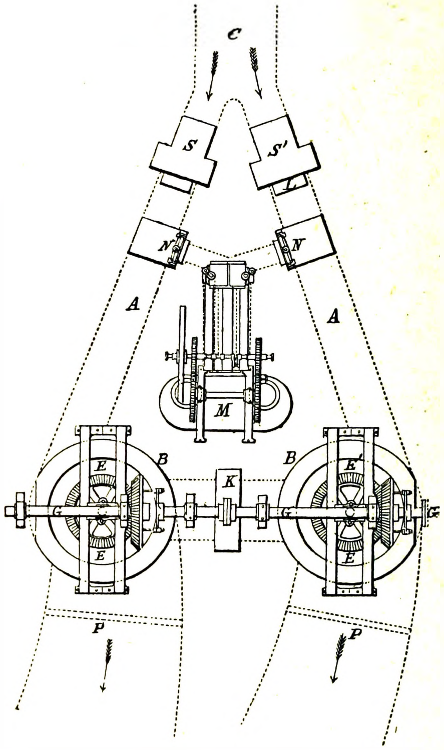
The pumps are carried by collars on the shafts and are keyed upon them; the pumps and shafts are held central by girders fixed across the wells and stayed by short girders at right angles. The lower bearings of the shafts are cased with gun-metal, and work in lignum-vitæ bushes without any end bearings, H, Fig. 1888; and the bearings at the upper ends of the shafts are formed of a series of collars working in gun-metal, I, Fig. 1886, which carry the weight of the pumps and shafts and of the column of water in the centre opening of the pump. By means of screws the level of the pumps can be adjusted, so as to give a minimum clearance between the rotating part of the pumps and the fixed part, with the least loss from clearance and the least amount of friction.

The pumps are 8½ ft. diameter, and the suction pipes 4¼ ft., increasing to 6 ft. diameter at the rose end. The pumps, Figs. 1888, 1889, are of cast iron, and of a form that has been adopted by Geo. B. Rennie, who has found, by experiment, that the ordinary form of centrifugal pumps, with the outflow abruptly at right angles, or nearly so, to the inflow causes a considerable loss in the delivery of the water. The result was found to be that at all heights, the percentage of duty was the greatest, when the arms had a curve formed by the resultants of the circumferential velocity at any point, and the radial velocity of the water at that point. This curve was consequently adopted for the arms of the pumps, Fig. 1889; it has a close resemblance to the curve advocated by Appold.

1886.



1887.



The operation of emptying the docks is performed as follows;—At the commencement of the pumping, the water standing at the same level in the dock as in the basin, namely, 27 ft. above the sill and 30½ ft. above the floor of the dock, the sluice K between the two pump wells is closed, Fig. 1886, and each pump has then a separate suction from the main culvert of the docks, and discharges independently into the basin; but both pumps are driven at the same velocity by the engine and first motion shaft. This continues until the water is lowered the first half depth of 15 ft. down to the broad altar level; the suction of the upper pump from the main culvert C is then closed by the sluice L, Fig. 1887, and the sluice K between the two wells is opened, so that the lower pump drawing from the main culvert discharges into the suction of the upper pump, which in its turn discharges into the basin. Thus, although the total lift for pumping increases from zero up to 30½ ft., each pump can be proportioned as regards both size and velocity for a lift increasing from zero up to only about 15 ft.

With this arrangement the average discharge a minute for each pump, as the water falls through successive depths of 5 ft. from the highest level, was estimated to be as follows;—

1st 5 ft.,	pumps making	about	70	revs. a min.	discharge each	245	tons a min.
2nd 5 ft.	,,	,,	80	,,	,,	206	,,
3rd 5 ft.	,,	,,	94	,,	,,	147	,,

The total quantities of water to be discharged for emptying each dock through the successive 5-ft. depths are about as follows;—

1st 5 ft.,	6,300	tons, occupying	26	min.
2nd 5 ft.,	5,980	,, ,,	29	,,
3rd 5 ft.,	5,720	,, ,,	39	,,
Total	18,000	tons, occupying	94	min.

Consequently the docks would be emptied the 15-ft. depth down to the broad altar level in less than 1¾ hours, when the two docks are being pumped out together by the pair of pumps.

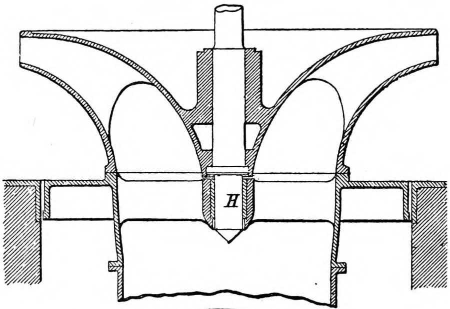
The quantities of water to be discharged for emptying the lower half of each dock through successive 5-ft. depths are;—

1st 5 ft.,	4,600 tons,	occupying	38 min.
2nd 5 ft.,	4,200 ,,	,,	41 ,,
3rd 5 ft.,	3,200 ,,	,,	44 ,,
Totol	12,000 tons,	occupying	123 min.

The discharge of the two pumps together through this lower portion, was estimated to be equal to the discharge of each of them separately through the upper portion, making the time about 2¼ hours for emptying the lower half of the two docks from the broad altar level to the bottom of the docks. The total time for emptying the two docks is thus 4 hours.

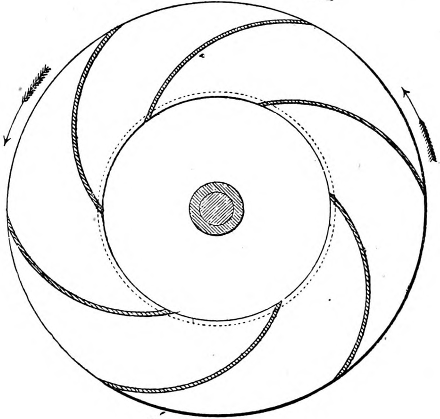
The sluices, with the exception of two, are single faced, of cast iron, with gun-metal faces, Figs. 1886 and 1887. The hydraulic cylinders by which the sluices are worked are proportioned so that any sluice may be raised or shut in about two minutes; the cylinders are lined with copper, and are double-acting. Wherever the height above the head of the sluice is limited by the ground level, the hydraulic cylinders are placed horizontally underground, and the sluices are then weighted sufficiently to shut them against the pressure of the head of water. Where the pressure from the head of water in the culverts may be in either direction, two separate sluices are used in the same well, with their faces in opposite directions; excepting in the case of the sluice K, Fig. 1886, between the two pump wells, and also the one situated at L in the branch suction culvert to the upper pump, where special and somewhat novel arrangements are adopted.

1888.



The sluice at L, in the branch suction culvert to the upper pump, is made with two parallel faces, with a small clearance between these and the iron frames fitted in the masonry, in order that it may go down easily into its place; the pin-joint in the rod working the sluice is also made with a similar clearance, so that the sluice door is free to close tight upon the face against which the pressure forces it. By this arrangement considerable economy is effected, as an additional ram is saved, and there is also less cost in the manufacture of the sluice thus made than in making two independent sluices.

The sluice K, between the pump wells, is made of a wedge shape, fitted with hard wood on the bearing surfaces, resting on granite facings. The hydraulic cylinder for this sluice is horizontal and single-acting, the weight of the sluice being sufficient to close it.



Scale = 1/48

1889.

For drainage purposes, a separate well is provided at M, containing two bucket-lift pumps of 20 in. diameter and 33 in. stroke, worked by a small pair of engines with 14 by 18 in. cylinders. These are almost constantly at work for pumping out the water leaking into the emptied docks; a pair of sluices at N N, worked by hand, admit the water from the branch suction culverts A A to the drainage well M. These pumps also give the means of emptying the two main pump wells, so that the main pumps can be left dry and accessible at all times when they are standing. Self-acting flap-valves opening outwards, made of wood and leather, are placed at P P in each of the main discharge culverts, for preventing the discharged water from returning into the pump wells.

PYROMETER.

In nearly all the processes connected with metals and their alloys, constant reference is made to the temperature at which certain operations have to be performed. The instruments used for observing these temperatures are known as the thermometer, or measure of heat; and the pyrometer, or measure of fire.

The first is employed for all temperatures up to that at which mercury boils; the second is more particularly used to ascertain those higher temperatures in which the nature of a thermometer will not allow of its direct use. The thermometer deals with a range of heat comparatively easy to register and observe, and reliable instruments may now be obtained, regulated to an extreme degree of precision. Although much ingenuity has been employed in the construction of pyrometers, great doubt is felt with regard to their accuracy, more particularly at very high temperatures. There is yet room for improvement in this respect, as a delicate and reliable instrument for the observation of high temperatures would be of great service to scientific men and manufacturers.

In measuring the melting-points of metals, the temperature must be taken just before melting takes place, because at the moment of liquefaction a certain quantity of latent heat is absorbed, and beyond that point the temperature of the melted metal might rise considerably, and make the observation incorrect; as a thermometer cannot then be directly applied, a pyrometer is employed.

Numerous pyrometers have been devised by utilizing the expansion of air from heat. This is the principle of the pyrometers of Schmidt, Petersen, and Pouillet. Where these instruments can be conveniently applied, they are capable of yielding fairly accurate results.

The final indications of this kind of pyrometer will of course be arrived at by the laws of expansion of air and gases by heat. Regnault gives the amount of expansion of atmospheric air heated from 32° Fahr. to 212° Fahr., as ·3665 or ·3670 on its original bulk at 32° Fahr.

Wedgwood's pyrometer was founded on the property which clay possesses of contracting at high temperatures. The apparatus consisted of a metallic groove, 24 in. long, the sides of which converged, being half an inch wide above, and three-tenths of an inch below. The clay was made up into little cylinders, or truncated cones, which fitted the top opening of the groove when they had been heated to redness; and their subsequent contraction when still further heated was shown by their sliding gradually down the groove till they arrived at a part of it through which they could not pass.

This measure of heat is no longer employed by scientific men, as its indications cannot be relied upon, owing to the variations in the quality of clay; but there are times when the principle involved in its construction may be of use for rough approximations of high temperature.

Wedgwood divided the whole length of the groove into 240°, each of which he supposed equal to 130° Fahr., and he fixed the zero of his scale at the 1077th degree of Fahrenheit's thermometer.

He assumed that the amount of contraction of the clay would be always proportionate to the degree of heat to which it might have been exposed. This is erroneous, for it is found in practice that a long-continued and moderate heat will cause the clay to contract to an equal amount as a fiercer heat applied for a short period.

Another proof of its inaccuracy is to be found in the absolutely impossible temperatures recorded in some chemical books as being obtained by this instrument.

Since the invention of the above in 1782, a number of other heat-measurers have been constructed, of which we describe the most useful and reliable.

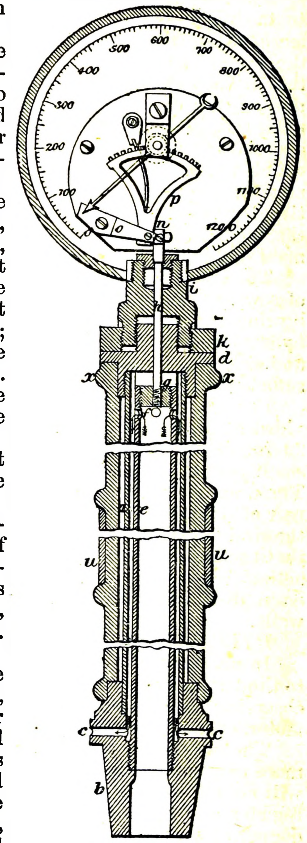
The great majority of substances expand when heated, more particularly the metals, and steel when heated expands more when tempered than when not tempered.

In Daniell's pyrometer, the temperature is measured by the expansion of a metal rod, enclosed in a case composed of black-lead and clay, in fact, of the same composition as a plumbago crucible, in which is drilled a hole $\frac{3}{10}$ of an inch in diameter, and 7½ in. deep. Into this hole the cylindrical rod of soft iron or platinum of nearly the same diameter, and 6½ in. long, is introduced, so as to rest against the solid end of the hole; and upon the outer or free end of the metallic rod rests a cylindrical piece of porcelain, called the index. When the instrument is heated, the metal, expanding more than the case, presses the index forward, which, by means of a wedge, is kept in the position to which it has been forced, when the instrument is removed from the furnace and cooled. A scale is then attached to measure the precise extent to which the index has been pushed forward by the metallic rod; it thus indicates the difference between the elongation of the platinum rod, and that of the black-lead case which contains it. For its indications to be absolutely correct, it is necessary that the rod and the case should expand uniformly, or both vary at the same rate.

A very inconvenient circumstance attending the employment of this instrument is, that no indications of temperature can be obtained by it until it is removed from a furnace.

Gauntlett's pyrometer is constructed on the principle of observations made upon the differential expansion of rods, or tubes, of brass and iron. This cannot be relied upon beyond a point approaching red heat, at which permanent elongation of the metals sets in. Such pyrometers are within limits, however, very useful, and several varieties are made, of which two are illustrated, Figs. 1890, 1892, the former showing Carsatelli's and the latter Bailey's.

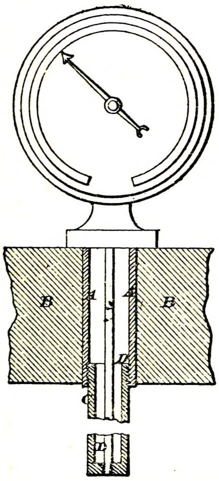
1890.



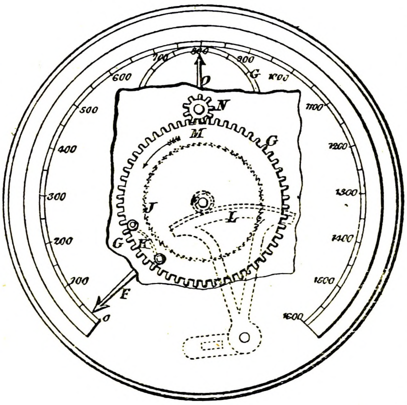
The instrument made by Carsatelli, Fig. 1890, consists of a tube *a* of iron or other metal, screwed at one end into a metal cone *b*, having through it a number of transverse holes *c*, and at the other end to a flanged socket *d*, and inside the tube *a* there is a second or smaller tube *e* of metal, the ratio of expansion of which by heat is different from the outer tube. This inner tube *e* is also screwed at one end to the metal cone *b*, and has at the other end transverse holes *f*, and a plug *g*, into which is screwed one end of a rod *h*, which passes through a stem *i*, screwed and adjusted to the flanged socket on the top of the outer tube, and afterwards held firm by the nut *k*; and to this stem *i* is fixed a case provided with a dial. The other end of the rod *h* is in contact with a small block *n*, pivoted to an arm *o* of the toothed quadrant or segment *p*, gearing into a pinion on the spindle carrying the index hand, and as the rod *h* is moved up or down, according to the expansion or contraction of the tubes of metal, it gives motion to the toothed quadrant and pinion, and consequently to the index hand. The hot blast is passed through the instrument by inserting the cone *b* into the socket of the plug of the tuyere-tube, or other suitable place, the current passing through the inner tube through the holes at the top, between the inner and outer tubes, and out through the holes *e* in the cone. The outer tube *a* has a cover of wood, or other non-conducting material, encircled by felt or cloth *u* for preventing the radiation of heat from the instrument, and enabling it to be handled comfortably.

In W. H. Bailey's pyrometer, Fig. 1891, an attempt is made to preserve a portion of the length of the rods employed non-pyrometrical, in order that when it becomes necessary to pass the stem of the pyrometer through brickwork, as in the case of a furnace, that portion of the stem which is actually in the heat shall alone be utilized for pyrometrical purposes; thus a more accurate indication of the heat is obtained, and the permanent expansion of the materials reduced to a minimum.

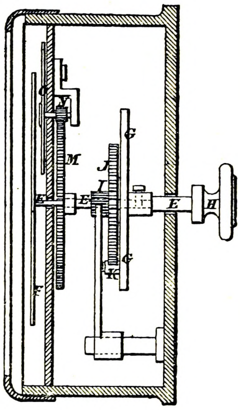
1891.



1892.



1893.



Arrangements are made to return the index finger to zero when required, and there are also two hands, one of which makes a complete revolution for every degree indicated by the other, and thus at every revolution of the smaller hand the larger hand will only move one degree, but in its whole revolution will indicate the total heat.

In Fig. 1891, A is a wrought-iron tube, passing through the brickwork B, and having a brass or copper tube C, screwed in on the other side of the brickwork. D is a common wrought-iron rod connected with a quadrant at one end for actuating the index spindle, and which rod, being of the same material as the tube A, only that portion of its length which extends beyond the mouth of the tube A, into the furnace or oven, has any influence in indicating the temperature of the furnace or oven, by the difference in its expansion as compared with the brass or copper tube C, but any other materials which expand unequally may be employed, either in the form of rods or tubes, provided that the tube which passes through the brickwork is compensated for, by an inner tube or rod of the same material and length as the tube or casing A.

In Figs. 1892, 1893, E is the index spindle carrying the index hand F, disc wheel G, and mill-headed knob H, all firmly secured upon the spindle. I is a toothed pinion combined with a ratchet wheel J, which is mounted loosely upon the spindle E, but is compelled to turn with it in one direction by the application of a spring pawl K, mounted upon the face of the disc wheel G, and taking into the teeth of the ratchet wheel J; the pinion I gears with the ordinary toothed quadrant L, which is connected with the internal tube or rod, upon the expansion of which, as compared with the external tube, the indicating depends. This pinion acts upon the spindle E as if it was fixed thereupon, but if, through permanent expansion of either of the differently expanding materials employed, the index finger F fails to return to the starting-point, by turning the knob or handle H, the spindle may be turned in the direction of the arrow without affecting the position of the pinion, as the spring pawl K permits the disc wheel G to turn independently in that direction, and thus the instrument may be adjusted to the greatest nicety. To ascertain the fractions of a degree of temperature, a toothed wheel M is fitted to the spindle E and gearing with a pinion N turns a pointed hand O, indicating upon a smaller dial.

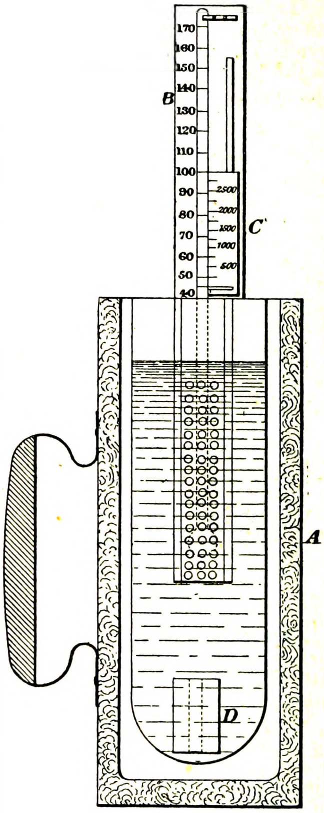
MacDonald's pyrometer is a metal or porcelain tube, filled with anhydrous nitrogen, and combined with a Bourdon gauge, provided with suitably graduated dials to indicate the temperature.

Maier's pyrometer consists of an iron tube enclosing a central rod or axle, round which a spiral metallic ribbon is wound, one end of the axle being fitted to the tube. During the process of heating the ribbon is unwound, and causes the rotation of the central rod, which communicates the rotary movement, by suitable mechanism, to the pointer moving over the dial.

In Steinle and Hartung's pyrometer three tubes are arranged, one within the other, the two inner tubes being perforated throughout their entire length, and supporting the usual dial and indicator. The inner tubes also project beyond their covering. The centre rod is formed, for some part of its length, of a solid stick of graphite. As soon as this is applied to heat its length is altered, and an indication of the same transmitted to the dial. Means are provided for regulating the position of the pointer.

The principle of the measurement of high temperatures founded upon the quantity of heat imparted to a given bulk of water, at some known temperature, by plunging therein a heated body, is that upon which Wilson's pyrometer, Figs. 1894, 1895, is based.

1894.

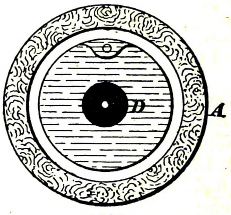


The instrument consists of a copper vessel A, capable of holding rather more than a pint of water, and well protected against radiation by having two double casings around it, the inner containing air, and the outer filled with felt. A good mercury thermometer B is fixed in it, having in addition to the ordinary scale a small sliding scale C, graduated and figured with 50° to 1° of the thermometer scale; there is also provided a cylindrical piece of copper D, accurately adjusted in size so that its total capacity for heat shall be $\frac{1}{50}$th that of a pint of water. In using the pyrometer, a pint of water is measured into the copper vessel, and the sliding pyrometer scale C is set with its zero at the temperature of the water, as indicated by the mercury thermometer B. The piece of copper is then attached to a piece of wire placed in the substance, the temperature of which it is wished to ascertain, and is allowed to become heated for about two minutes, when it is quickly dropped into the water in the copper vessel, and raises the temperature of the water in the proportion of 1° for each 50° of temperature in the copper; the rise in temperature may be read off at once on the pyrometer scale, and if to this is added the actual temperature of the water, as shown on the scale of the mercury thermometer, the exact temperature is obtained. This pyrometer is found to be more accurate than others for such temperatures as will not melt platinum; for still higher temperatures a piece of platinum would be used instead of copper, and the instrument would then be available up to the highest temperature that platinum would stand. Of course this instrument cannot be used for taking observations in inaccessible places.

Another mode of utilizing a thermometer in measuring high temperatures approximately is Main's pyrometer, shown in Fig. 1896. Here D represents a hot-blast pipe, and A the apparatus, which consists of three concentric cylindrical vessels of copper or brass. In the inner chamber a delicate thermometer is placed, and the hot blast conducted by the tube C from the pipe D circulates through the second chamber, passing out by the tapered nozzle E. The outer space is filled with a substance of low conducting power.

The temperature indicated by the thermometer does not, of course, represent the actual temperature of the hot blast; but to ascertain this, it is only necessary to insert a metallic pyrometer in the hot-blast pipe D, and compare the relative indications in order to fix a ratio. Any ratio desired may be obtained by a simple adjustment of the bore of the tapered nozzle. When the object is only to regulate the temperature of the blast this adjustment is not required, it being sufficient to note the degrees indicated by the thermometer when the blast is at the ordinary working temperature, and thereafter maintain it at that point.

In Tremeschini and Lion's pyrometer, a fire-clay tube is introduced into the heat, and the hot air conducted from it into a copper tube, contiguous to which a sensitive metallic thermometer is placed, this latter being so arranged that its distance from the copper tube is adjustable. If the thermometer is placed at such a distance that it always shows a particular degree of heat, then the temperature to be measured corresponds to the square roots of the distance between it and the copper tube.



1895.

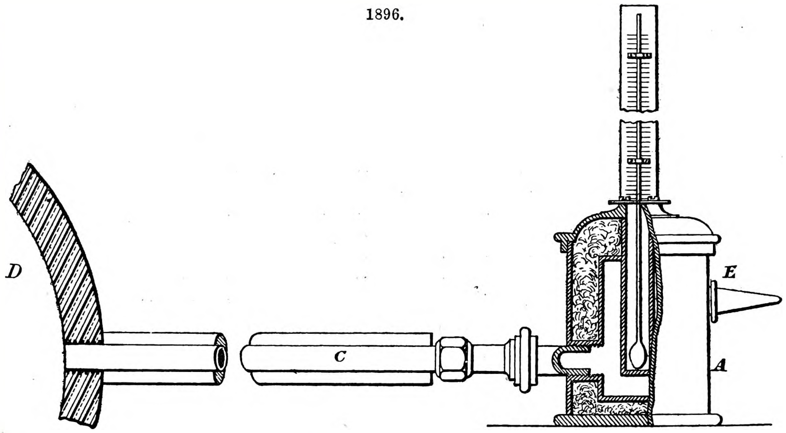
The electrical resistance of metal conductors depends upon their dimensions, material, and upon their temperature; an increase of the latter causing a corresponding increase of resistance. The law of this increase is known. Thus, the resistance of a conductor being ascertained at 0° Centigrade, it can be calculated for any temperature, and, vice versâ, if the resistance can be found by measurement, the temperature can be calculated. And this is the principle upon which Siemens's electrical pyrometer, Figs. 1897, 1898, is based.

A platinum coil of a known resistance at 0° Centigrade is coiled on a cylinder of fire-clay, protected by a platinum shield P, which is placed in an iron or platinum tube, and then exposed to the temperature to be determined. Leading-wires *l l* are arranged to connect this coil with an instrument suitable for measuring its resistance, and from this resistance the temperature can be calculated. These leading-wires can be brought from the furnace into an office, where the temperature could be read off, and recorded as often as required.

The resistance-measuring instrument supplied for the purpose is a differential voltameter. This consists of two separate glass tubes, in each of which a mixture of sulphuric acid and water is decomposed by an electrical current passing between two platinum electrodes. The gas which is generated is collected in the long cylindrical and carefully-calibred top of the tube, and this quantity is read off by means of a graduated scale fixed behind the tubes.

Movable reservoirs are provided, communicating with the tubes, to regulate the level of the liquid. The current of the battery is divided by passing a commutator into two circuits, one of which consists of an artificial resistance in the instrument and the platinum electrodes in one tube; the other, of the resistance to be measured and the electrodes in the other tube. The quantities of gas developed in the two tubes are in reverse proportion to the resistances of their respective circuits, therefore one of the resistances, namely, that in the instrument, being known, the other can be calculated.

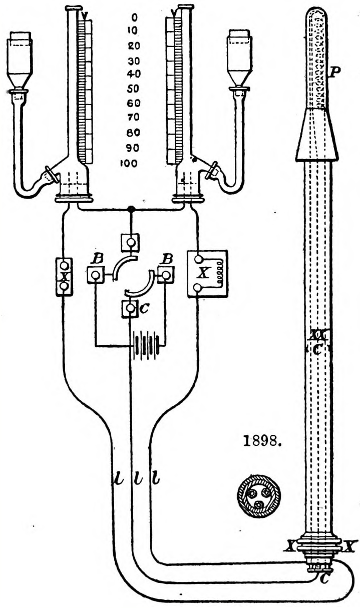
1896.



The makers give the following directions for use;—Fill the battery glasses with pure water, or, in case of the power of the battery decreasing, with a solution of sal-ammoniac in water. Connect the poles to B and B^1 on the commutator. Expose the small end of the pyrometer tube, as far as the cone, to the heat to be measured, and connect the terminals X, X^1, C, on the voltameter.

The differential voltameter is to be filled with the diluted sulphuric acid through the reservoirs, the indiarubber cushions being lifted from the top of the tubes. The commutator is to be turned so that the contact-springs on both sides rest on the ebonite. The liquid in both tubes is to be regulated to the same level, 0° of the scale, and the indiarubber cushions to be let down again. The commutator is then given a quarter of a turn, and the development of gas will commence almost immediately. The commutator is turned half round every ten seconds to reverse the current, which is kept passing until the liquid has fallen in the tubes to at least 50° of the scale; the commutator is then put in its first position, so that the contact-springs rest on the ebonite; the level of the liquids read off on the scales marked V V, and the scale marked V^1; and these numbers found in the table. The intersecting point of the lines starting from these figures gives the resistance of the exposed coil in black, and its temperature in red figures.

1897.



1898.

A satisfactory method for some purposes is to use alloys and metals whose melting-points had been previously determined, and E. Buchner has designed an apparatus, in order automatically to register the exact moment at which a given alloy melts in the interior of a furnace. It consists of a vertical tube of refractory material, which dips deeply into the muffle; inside this a small crucible is hung from a scale beam above; in the bottom of the crucible is a hole, so that when the alloy melts it runs through into a dish suspended underneath. This causes the scale beam to rise, and the motion of the beam, by electrical contact, rings a bell, and marks a dot on a sheet of paper travelled by clockwork; this registers the exact time at which the melting-point is reached. The melted metal can be lifted out and preserved for future use.

ROAD LOCOMOTIVE.

Amongst the component parts of a road locomotive or traction engine, the driving wheels perform the most important functions. They may be classified under the heads of elastic, flexible, and rigid.

An elastic wheel is one which is sufficiently resilient to answer the purpose of bearing springs, but its circumference does not necessarily deviate from a circular form by the pressure of the tread. A flexible wheel is one whose treading face suffers a material change of form as it rolls along, and in addition to the faculty it possesses of acting as a spring, it has a large portion of its periphery continually in contact with the ground. Adam's road wheel, Fig. 1907, and Mackinder's road wheel are elastic, but their rigid tires cannot deviate from the circular form. Thomson's indiarubber wheel, Fig. 1899, and Bremme's steel tire wheel, Fig. 1911, are flexible, as their tread yields as they roll along. Therefore, an elastic wheel merely answers the purpose of bearing-springs, and does not practically increase the bite; while a flexible wheel forms a spring, and also increases the adhesion. All other wheels are classed as rigid, because they do not yield to the inequalities of the road.

The adaptation of locomotives to common roads has, for the last fifty years, been a matter of continuous experiments, accompanied by many failures. That it is difficult to design a locomotive which shall work as well on the highways as thousands of similar engines work on rails, is shown by the fact that during half a century many of the best mechanical engineers, have from time to time, made road locomotives and experimented with them; and yet, even up to the present, with one or two exceptions, they are unable to produce more than an approximately perfect road locomotive, either for passenger or for ordinary goods traffic. The farmer's engine is the only type which has, as yet, given any really satisfactory results.

The following table, compiled by John Head, partly from data by Crompton, and partly from other sources, will show the resistance of smooth, rigid wheels, in lb. a ton, on different surfaces:—

On very good pavement	35 lb.
„ good macadam	60 „
„ ordinary macadam	90 „
„ newly-laid gravel	200 „
„ soft grass land	300 „
„ newly-laid metal	440 „
„ a well-laid railway with moderate gradients	8–10 „

From which it appears, that even when the road is in the best order, the rolling resistance is about eight times that on rails. With the road in an ordinary state, it is from ten times to twelve times, while, on newly-laid metal, the rolling resistance becomes nearly fifty times that on rails. As almost all roads contain inclines of 1 in 20, or 1 in 30, and as many of them contain inclines of 1 in 10, it will be seen that the actual pull, required to move 1 ton over many portions of macadamized roads, amounts, in some cases, to more than 100 times that on a railway with moderate gradients. The difficulty of obtaining sufficient adhesion, and the wear and tear caused by rigid wheels without springs, have, from time to time, led to the trial of various devices for overcoming these defects; but extended experience seems to show, that a rigid wheel, with wrought-iron diagonal bars on the periphery, is the cheapest driver, and that, in many cases, it is sufficiently reliable for the class of work for which road locomotives are usually required. At the same time, a great demand exists for a reliable flexible wheel, for use under certain circumstances where the rigid wheel is almost useless.

The different types of wheels are classed by Head as follows;—

For farm engines, used for thrashing, and for hauling light loads on an estate, steam ploughing engines, passenger engines, and for light loads at high speeds, rigid wheels and, in some instances, elastic wheels should be adopted.

For engines designed to ascend very steep gradients, and for engines used for hauling heavy loads on causeways or stone pavements, flexible wheels are required.

The following is a description of some of the principal driving wheels which have been designed;—

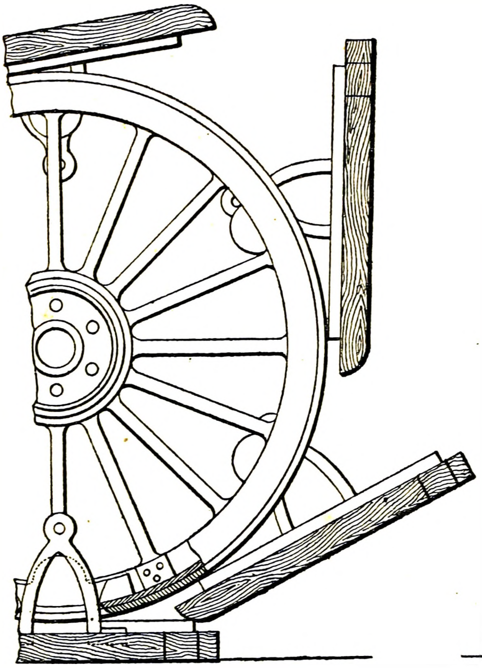
The first wheel which came into extended use in traction engines was termed Boydell's endless railway. It consisted of large, flat segments of rails, so jointed round the wheel, that it ran on a species of continuous tramway, Figs. 1899, 1900. This wheel was introduced in 1846, for facilitating the draught of ordinary carriages over soft ground, by means of an extended bearing surface, which prevented the wheels sinking. It was partially used for that purpose for several years before it was proposed to adapt it to a locomotive. One of the principal objects the inventor wished to attain, was the transport by steam of artillery over roads impassable by horses or oxen. Boydell's wheel, when tried, gave the most satisfactory results as regards the increase of adhesion, and it was shown that it could run with facility over soft land upon which a horse could not move a light cart. The great surface of the shoes in contact with the ground, enabled it to haul great weights over bogs, and to perform many other feats, which quickly brought the engine into notice. Indeed, its pulling power was so great, that a single driving wheel gave more than sufficient bite for all ordinary hauling work; and, consequently, several engines were constructed with only one side of the machine fitted with the travelling trams, a good plan to save expense, but one calculated to destroy the general efficiency of a locomotive, as its facility of steerage is thereby much impaired.

Boydell's wheel clearly proved that a large surface in contact with the ground tended to an increase of efficiency, but at a great outlay of wear and tear. There was no elastic medium to deaden the concussion, and the whole apparatus went clattering along, an extraordinary combination of inharmonious mechanism. However, the arrangement was continued for many years.

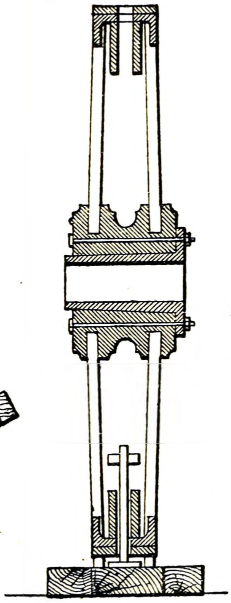
Some short time after Boydell had brought his engines into public use, and when the great advantages of increased adhesion had become clearly known, Bray, of Kent, brought out his spudded wheel, Figs. 1901, 1902, by means of which it was hoped to gain sufficient adhesion, without complexity and liability to breakage. Bray's wheel had a rigid tire fitted with short, strong spikes to dig into the road surface as it rolled along. These spuds could, by an eccentric, be drawn in below the wheel surface, so that it then ran with merely a smooth tire, but when they were projected it was a rigid spiked wheel. The bite of such a wheel on cobble-stones, between which the spuds inserted themselves, was equal to cog-gearing, and on macadam the peculiarly shaped spuds inserted themselves into the surface of the road, and produced a similar effect, but to a smaller extent. This plan answered well for some roads, but it was evidently not suited for general use on account of the damage done to the highways, and the continued breakages in the mechanism of the wheels, caused by the unequal strains on the connecting rods of the spuds.

R. W. Thomson, of Edinburgh, in 1867, constructed a wheel consisting of a very light wrought-iron drum, 4 ft. diameter, by 15 in. wide, with flanges, 1 in. high, on either side. Outside this drum was stretched a flat indiarubber band, or tire, 12 in. wide by 5 in. thick. The wheel ran with the indiarubber in contact with the ground. It was found to slip on damp roads and greasy mud. To obviate this, Thomson covered the indiarubber tire with flat steel plates, or shoes. These were turned over at the ends and joined together by ordinary flat links, as in the upper parts of Figs. 1903, 1904, some of which were of different lengths, in order to compensate for the elongation of the chain by wear. This species of armour was very troublesome, owing to the continuous breakage of the link pins, and the difficulty of keeping the tire in its place unless the shoes were very tight.

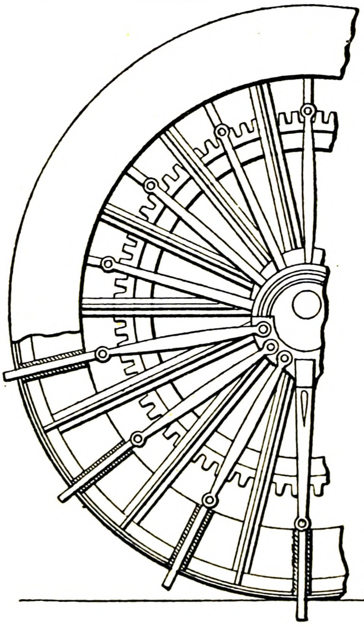
1899.



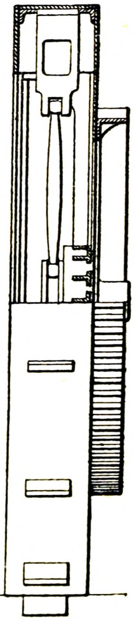
1900.



1901.



1902.

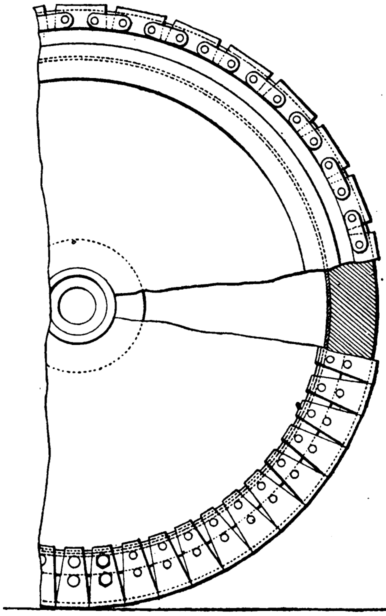


Another system of protecting the indiarubber tire was invented by Thomson, and improved by Burrell, it is seen in the lower parts of Figs. 1903, 1904. In this case the steel plates touch each other outside the tire, and tapering at the ends, are turned down so as to lap over and clip the angle iron rim of the wheel on both sides, thus permitting the indiarubber to rotate, but preventing it from coming off sideways. The shoe is kept in position, on one side, by a plate fastened with two screws. This arrangement enables any one shoe to be disconnected without taking off all the rest. The system has been found to work well in practice, but experience has not yet shown what will be the wear between the clips at the end of the shoes, and the angle iron of the wheel.

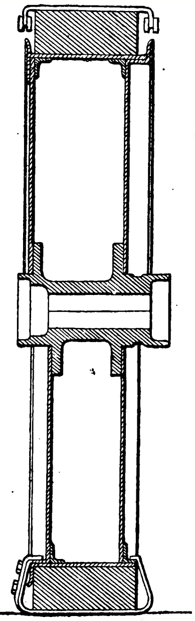
Aveling and Greig's improved shoe, Figs. 1905, 1906, formed of a strong plate turned over at both ends, each side finishing in the form of a hook which was attached to a loop at the end of a wrought plate sliding on the edge of the rim of the driving wheel. The shoes were fixed to the rim of the wheel instead of rotating with the tire. This description of shoe has been attached to several engines manufactured by John Fowler and Co., and has been in work for some time. It remains to be proved how the indiarubber tire will wear, when rotating inside the annular space formed by the fixed shoes and the outer surface of the wheel.

Much difficulty was experienced in the early trials of Thomson's wheel, owing to the convexity of the road forcing the indiarubber tire over the angle iron, thus necessitating guards to keep it in place. The shoes just described will not allow any play in the tire, but nevertheless a great wear and tear is continually taking place through the outward lateral pressure of the indiarubber.

1903.

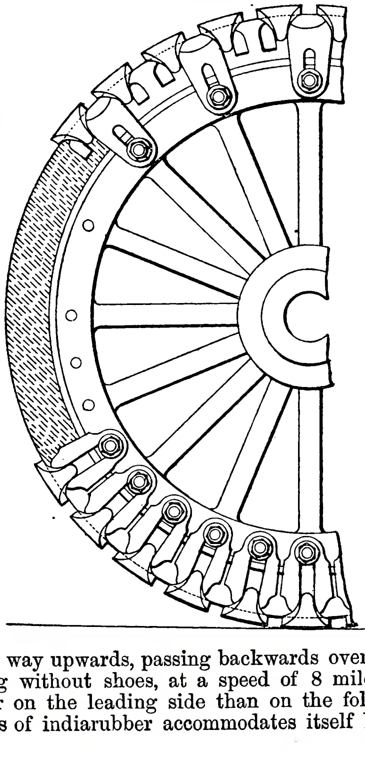


1904.

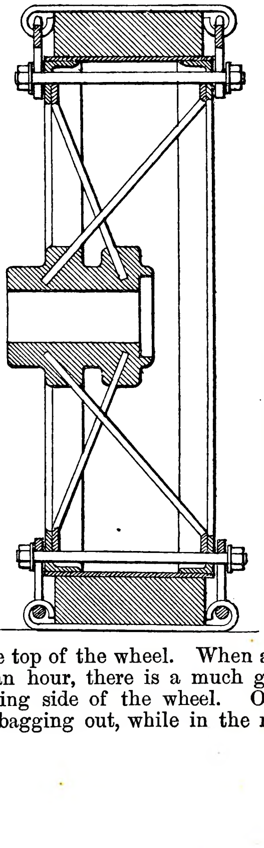


A very curious feature was discovered when working the indiarubber tire without shoes. The tire being loose on the drum, as the wheel revolves, a portion of the indiarubber is continually rolled out to the leading side, where it accumulates until, when running fast, the tire becomes several inches clear of the drum, and as this excess of indiarubber increases, it gradually escapes, by working its way upwards, passing backwards over the top of the wheel. When an indiarubber tire is working without shoes, at a speed of 8 miles an hour, there is a much greater amount of indiarubber on the leading side than on the following side of the wheel. On the leading side the excess of indiarubber accommodates itself by bagging out, while in the rear it is in a

1905.



1906.



state of tension, and tightly grips the iron wheel. From this action the indiarubber tire is continuously working round with a reverse motion to that of the drum. The rate of this motion depends upon the tightness with which it was originally stretched, its density, its thickness, and the weight on the wheel. If the wheel is very lightly loaded, the tire will scarcely move, while if it is heavily compressed, a great portion of it is rolled out towards the front, and the amount of the reverse-action becomes very great. Under ordinary circumstances the tire will move once round the drum in from 30 to 40 revolutions. It is evident that friction must take place in the indiarubber tire, from its contrary rotation round the iron drum, and also from the continuous change of form it undergoes. No experiments have, however, yet been made to determine the amount.

It appears certain that if indiarubber is used as a tire for the driving wheel of a road locomotive, it must be used in the form of a ring, and allowed to rotate. All experiments hitherto made for attaching it in blocks with cement to the periphery of the driving wheel, or of putting it on to the wheel in segments and fastening it by means of slings, have failed.

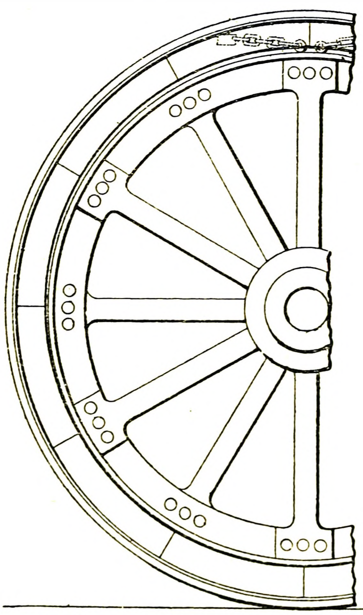
The indiarubber tire has the great advantage of being a perfect spring to the engine, and it forms a safe and sure brake. On good macadam its resistance is more than that of the rigid wheel, and on a rough or newly metalled road, owing to its great surface, it does not sink below the tops of the stones, while the rigid wheel consumes a great amount of power from sinking into the surface of the road with a crushing and grinding action. Over paved roads the indiarubber wheel, or any other equally elastic wheel, is decidedly superior to the rigid wheel, owing to the increased amount of surface of adhesion; in fact, it has been found that a flexible wheel is almost indispensable for all steam traffic on such roads, even with moderate gradients.

One of the principal drawbacks to the use of indiarubber tires is their great prime cost, which appears likely to increase instead of to diminish; also, the impossibility of finding a market for the sale of the worn-out indiarubber. With respect to their wear, much difference of opinion exists, but it is impossible to form any correct formula for depreciation, owing to the paucity of the experiments hitherto conducted.

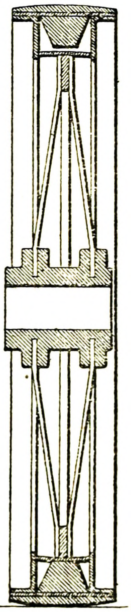
It is evident that, if the thickness of the tire is materially reduced, the power of the indiarubber to bear the engine easily is diminished, consequently a greater strain is brought upon each cubic inch of rubber than it is calculated to bear, thereby lessening the value of the tire as a spring to the engine.

Much may be said in favour of Thomson's tires, but the difficulties of protecting the indiarubber in a permanently satisfactory manner, coupled with the uncertainty of its action under peculiar circumstances, have to a great extent arrested its employment for the driving wheels of road locomotives.

1907.



1908.



Adams' road wheel, Figs. 1907, 1908, is purely elastic, and consists of an ordinary centre and arms, having a heavy T-iron rim, between which and the outer flat tier are inserted treading blocks of indiarubber, about 2 in. thick. These blocks, along with the T-iron rim of the inner part of the wheel, are kept in position by means of two angle irons riveted to the outer ring. A drag link connects the outside tire with the T-iron ring. These wheels, of course, do not increase adhesion, but they act well as moderate bearing springs, and give a great relief to the destructive jolting of an ordinary rigid wheel. They have been exclusively adopted by Aveling and Porter, of Rochester.

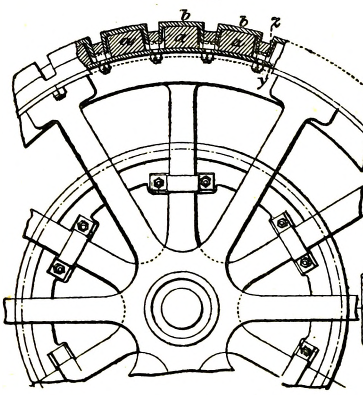
Mackinder's wheel, Figs. 1909, 1910, consists of an iron drum, surrounded by a series of transverse springs *a*, formed like those used for a railway truck, each fitted with an outer treading shoe *b*, sliding in guides. A set of these wheels, manufactured by Robey and Co., of Lincoln, has run for some time. The arrangement is heavy, and it is said that the sliding shoes wear rapidly through contact with sand and mud.

In Bremme's flexible steel tire wheel, Figs. 1911, 1912, the flexible tire is formed of one or more rings, each of which is constructed of one or more bands of steel or good wrought iron. In practice, the bands are made of steel, from ¼ in. to ⅜ in. thick, and from 2½ in. to 4 in. wide. The rings are fixed side by side, and are protected against the road by shoes or tread-pieces. To the tire are attached an adequate number of arms or links, which make the connection between it and the central part of the wheel, that is, the arms or links projecting a given distance beyond the periphery of the central part, are able to support the lateral thrust or pressure which the wheel may be exposed to, and are free to adjust themselves radially to any curve the elastic tire may assume under a dead load at the axle.

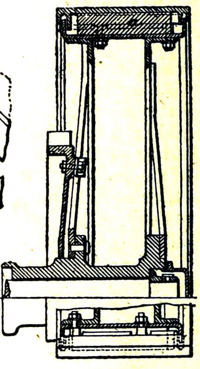
In driving wheels, the central part receives rotary motion, which by means of the arms is imparted to the tire. When the wheel stands on its tread, the whole load, acting at the centre is suspended from the upper portion of the tire, while its lower portion is perfectly free to deflect and flatten against the road, thus fulfilling the function of a spring, and producing increased contact surface with the road. These wheels have been fitted to one of Aveling and Porter's 6 horse-power Steam Sappers, at Chatham, and have been found to answer well.

Nairn's rope wheel was designed to have all the properties of the indiarubber wheel, at about one-quarter the cost. It consisted of two layers of rope, each 4 in. thick, coiled round a drum wheel, and protected by shoes on the outer surface. It was found in practice that when the rope was coiled loosely enough to flatten at the tread of the wheel, to the same extent as indiarubber, the resistance became very great, through the tire being soft and not elastic; and the rope was soon destroyed. If the coils were wound round as tightly as possible, the tire became almost rigid, and the wheel was not more efficient than one of wrought iron.

1909.

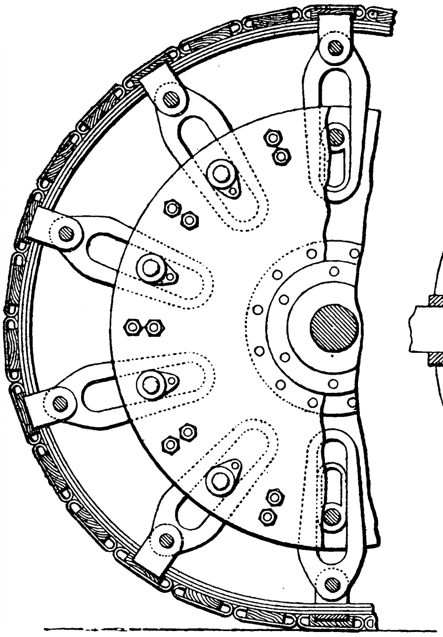


1910.

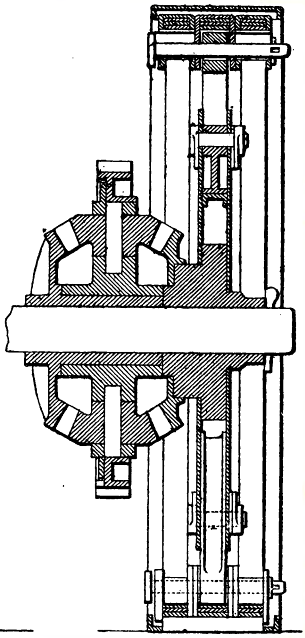


Several passenger engines have been built in Gt. Britain for use abroad, constructed on R. W. Thomson's system, and usually attached to a separate omnibus. Of these, one by C. Burrell, of Thetford, was an excellent specimen of careful design and workmanship; but the most worthy of notice were four 14-ton engines manufactured by Ransomes, Sims, and Head, for the Indian Government. Figs. 1913, 1914 give an elevation and half plan of one of these engines. They had cylinders of 8 in. diameter and 10 in. stroke, geared either 3·75 to 1, or 12 to 1, to 72-in. driving wheels. The engines made 150 revolutions a minute, which gave about 10 miles an hour for the fast speed, and 3 miles an hour for the slow speed. The boilers were vertical, on the Field system, the grate surface was 11 square feet, and the water surface was 177 square feet. The blast-nozzle had an adjustable cone, that the opening might be varied to suit either wood or coal. All the road wheels had Thomson's indiarubber tires, with linked shoes; the leading wheel had supplementary elliptical springs, so that the fore end adapted itself easily to the inequality of the road. The engine drew a 65-passenger two-wheeled omnibus. These locomotives are the most powerful passenger engines, and they have a large tank, and stowage for wood, so that they may run for 15 miles without stopping. They were to carry mails and passengers between two stations in the Punjáb, about 70 miles apart.

1911.



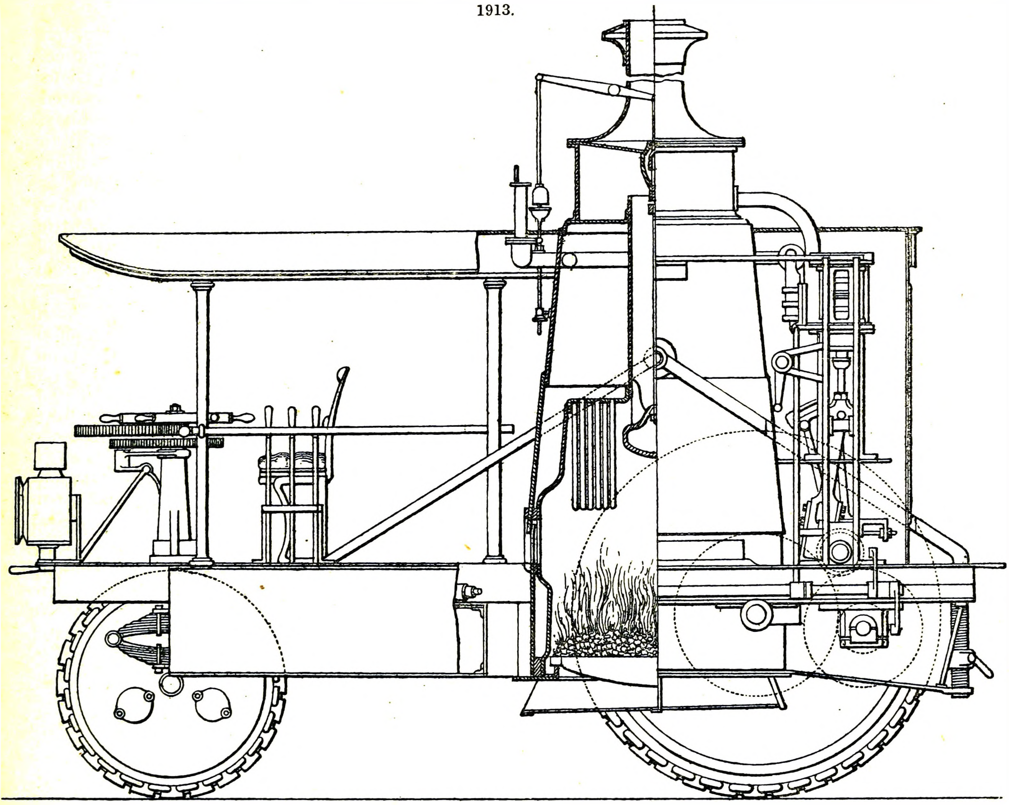
1912.

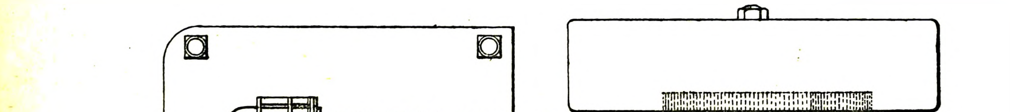


One of them, the Ravee, in October, 1871, made the double journey between Ipswich and Edinburgh, a total distance of 850 miles. The total weight of engine and carriage was about 19 tons. By the return journey the men had ample experience in working the engine, and the 425 miles took 9 days, giving 47 miles as the average distance a day, and a speed of 6·9 miles an hour for the time actually running; but on the last day the average speed was 9·69 miles an hour, whilst occasionally a speed of from 15 miles to 20 miles an hour was maintained for short distances.

Horse tramways are now laid in various parts of the world, chiefly in towns and their outskirts where roads are moderately level, and where the gradients do not exceed about 1 in 50, or 1 in 40; but sooner or later, steam tramways will form a more general means of transporting passengers and light goods. In order to make an engine which would compete successfully with the present system of haulage by animal power, it should be as light as possible consistently with the amount of traffic. J. Head considers that a small engine, weighing from 3½ to 4 tons when loaded, would be amply sufficient for drawing a tramway car of the present construction. The outward appearance should be sightly, and, as far as possible, similar in colour to ordinary vehicles running in the streets. The maximum speed should not exceed 10 miles an hour.

1913.





1914.

Several motive powers have been proposed for propelling street cars, and some of these, such as compressed air, ammonia, and carbonic acid, have been actually tried. Although these and other plans have been made to perform the functions for which they were designed, and might even be useful under exceptional circumstances, it may be taken for granted that the usual means of working street tramways, by mechanical power, will be by ordinary steam engines made and specially adopted for street traffic.

The modes in which steam power has been, heretofore, principally applied on tramways have been, by means of a car containing the goods or passengers, as well as the engine, running upon four, or more wheels, and by a detached engine drawing one or more cars.

The first of these systems has been successfully adopted on some lines in America, but it has the objection that the passengers do not like to be in such close proximity to the boiler; and, if generally adopted, the existing tramway companies would have to purchase entirely new rolling stock. This principle of construction has, however, the advantage that the whole weight of the car, engine, goods, and passengers, can be utilized for adhesion in ascending heavy inclines. The second system permits the use of all the existing rolling stock of the present horse tramway companies, with but little alteration, besides being more in accordance with the principle adopted on railways, and generally approved by the travelling public.

With steam as a prime mover, the difficulty is not how to supply the mere tractive force, but how to make the steam power so suited to street traffic that it shall not cause any annoyance. The main objection to an ordinary locomotive working in a street is the puffing blast, and various means have been tried to overcome this defect. First among them may be taken the heavy-geared dummy locomotives of New York. These are fitted with fans, blowing air into the fire-box, driven by a donkey engine and belt. The exhaust from the main engines goes into the tank, from which there is a pipe into the funnel. The donkey engine, however, requires continual attention from the fireman, who has to vary its speed as the locomotive is going up or down inclines, or proceeding at a fast or slow rate. Again, on the elevated railway in New York, a different plan has been proposed to gain the desideratum of a silent engine. The exhaust, as before, goes into the tank, from which there is a pipe into the funnel, but the furnace has a close ash-pan, into which is fitted Hancock's blower, consisting of a square funnel, into the wide end of which are directed nine jets of steam, each $\frac{1}{32}$ in. diameter, regulated by the fireman as the pressure varies.

One of the best street tramway locomotives yet proposed is that designed by Leonard J. Todd, of Leith. It is, however, only intended for light traffic. The driving motion is placed in a close box on the top of the boiler, so that it may be kept free from dirt and readily accessible. The driving wheels are of the Mansell construction, 6 ft. diameter. The cylinders are doubled, each 5 in. diameter and 9 in. stroke, and the working pressure is 150 lb. a sq. in. The wheels are fitted with steel tires, and motion is given to them by a single pinion and wheel confined in an air-tight case, arranged to give a maximum speed of about 10 miles an hour. One of these locomotives for hauling a single 40-passenger car is calculated to give an effective power of 12 horse-power, and it weighs when loaded 3½ tons. An engine of the same construction for two cars, with a maximum of 20 horse-power, will weigh 5 tons. A silent blowing fan is placed in direct communication with the close ash-pan, and one end of its spindle carries a bucket wheel, on to which the exhaust from the cylinder is directed through an adjustable nozzle. After thus driving the fan the exhaust enters the tank, where any water is deposited, and the uncondensed steam escapes into the funnel. A small steam pipe from the boiler is also attached to the fan casing, so as to drive the fan when the engine is standing. This apparatus, besides being silent, is self-acting, and it starts and stops with the engine. When going up an incline the back pressure increases and the fan runs fast; when going down hill, the steam being almost shut off from the engines, the speed of the fan is very much reduced, and the blast in the fire-box diminished. The fire-box is furnished with water grate bars to prevent clinkers. A skid brake is attached to the engine as forming a more sure method of slackening the speed than by a brake on to the wheels, and the handle on the engine is connected with the brake to the cars, so that the fireman may have the control of both engine and carriages.

A steam tramway car has been constructed by J. Grantham, in which the carriage is about 1 ft. 6 in. longer than the horse cars now in general use. It has two boilers on the Field system; these are placed in the centre, properly lagged, so that the heat does not penetrate into the body of the car. The two cylinders are fixed underneath the frame, and they are attached to the driving wheels in the same manner as in an outside-cylinder locomotive. The front wheels are placed on a sort of turntable frame, and they can be steered by the driver. The tires of the large wheels are flat, and the car is kept in position by four small guide wheels, which insert themselves in the grooves of the rails. The driver sits on the front platform, where the levers for working the engines are placed, and at the end of the journey they are detached and placed at the other end of the car. The boilers are supplied with coal from a hopper at the top, and the amount is regulated by a valve. The fire can be inspected from a door at the outside of the car.

Much may be said respecting the cost of haulage of goods by steam on common roads, but as no regular and continuous service has as yet been organized, all data on this subject must be considered approximate. Head states, however, the cost of haulage by steam, as given in the following table, may be considered as approximately correct, though, owing to the continuous fluctuations in the price of labour and materials, it is difficult to form an accurate estimate.

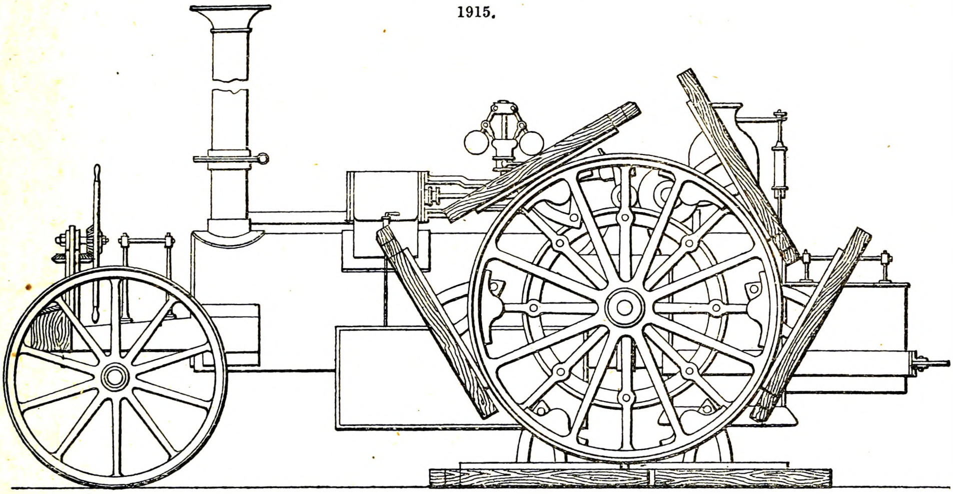
	d.		*d.*	
Horses on common roads	6	to	12	a ton mile.
Steam on common roads	3	,,	4	,,
Horses on tramway, if nearly level	2½	,,	3	,,
Steam on tramway	1½	,,	2	,,
Steam on railway	½	,,	1	,,

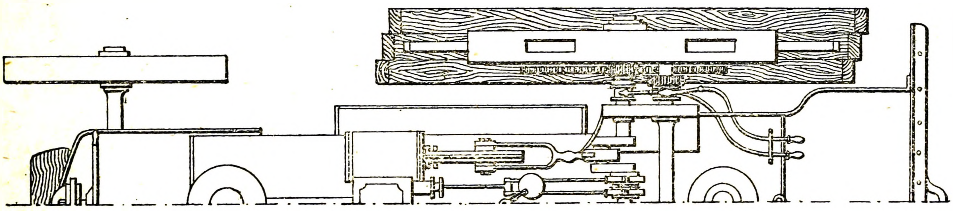
Heavy traction engines did not come into general use until about 1856. One of the first was Boydell's engine, Figs. 1915, 1916. The boiler was constructed on the locomotive type, with the cylinders on the top, and the motion of the engine was transmitted to the driving wheels, which were placed behind, by a pinion working into a large spur wheel fitted to the rim of the drum. The cylinders were double, 7 in. diameter and 12 in. stroke; the driving wheels were 66 in. diameter, and were geared 12–1.

A large number of these engines were manufactured, and were found to pass easily over soft ground, and the great surface of the paddles on the wheels enabled them to develop a high coefficient of adhesion. One of these engines made a journey from Thetford to London in 8 days, taking a gross load of 29 tons, but in point of speed and cost of haulage, the experiment was a failure.

Between 1856 and 1866 a few engines were fitted, in different parts of the country, with Bray's spudded wheels. These engines, when running with the spuds, pulled well on most roads, but they jolted so much that they seriously damaged themselves, and, in addition, materially injured the surfaces of the roads over which they ran; besides which, it was found difficult at times to force the spuds out of their sockets when they were required to be put in action. One of these engines, weighing 15 tons, readily took a gross load of 45 tons up a causeway incline of 1 in 30; the adhesion required to attain that result being 37 of the driving weight, an amount of hold which no smooth rigid wheel would give on a paved street unless assisted by special mechanism.

1915.





1916.

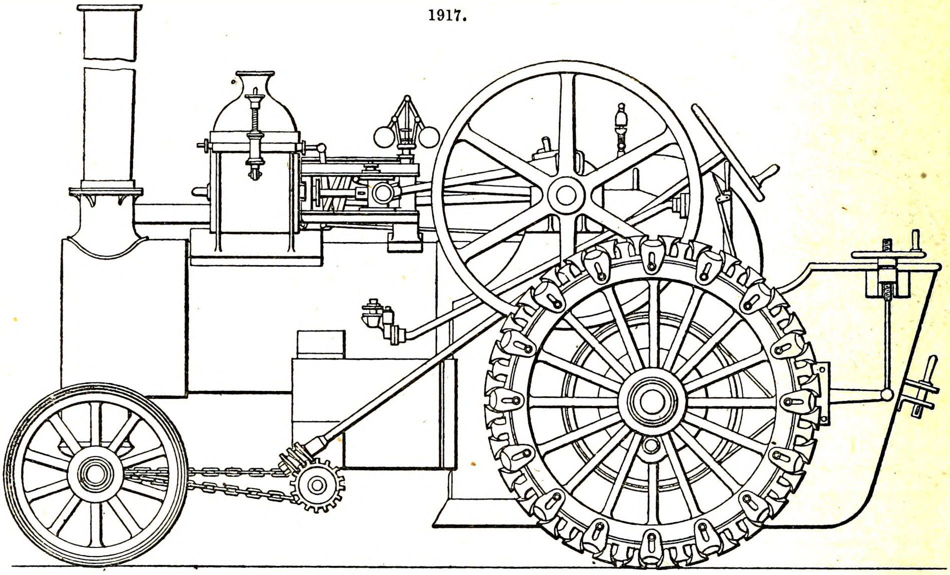
Taylor, of Birkenhead, a contemporary of Bray, brought out a novel design of road locomotive, which he called a steam elephant. The engines constructed upon this design had double cylinders, cog-gear, and very large driving wheels; the boiler was of the marine type, with return tubes. One engine, of 6 horse-power nominal, with cylinders of 5 in. diameter and 10 in. stroke, having 6 ft. drivers, and weighing 6 tons, was tested against a number of horses, by first ascertaining the greatest load it could draw, and then employing horses to accomplish the same task. It was found to pull as much as 12 strong horses.

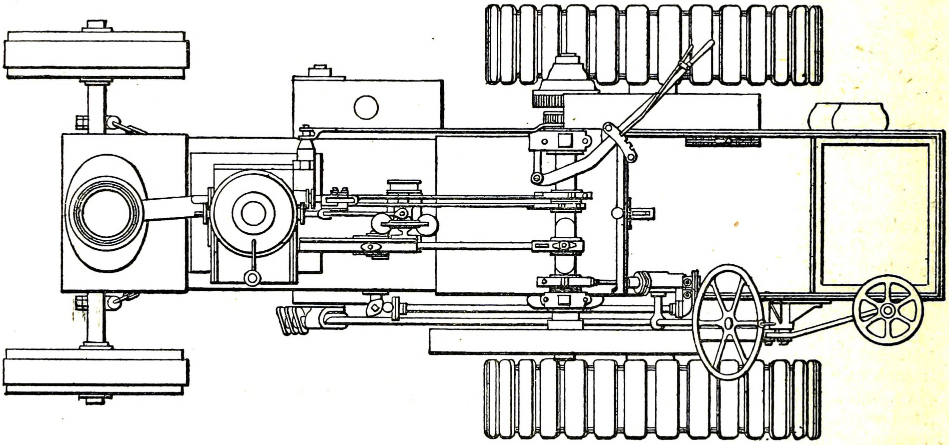
In 1869, Tennant, of Leith, designed a road locomotive. It had outside cylinders, $7\frac{1}{4}$ in. diameter and 10 in. stroke, two gears of $6\frac{1}{2}$ to 1, and 15 to 1 respectively, and rigid drivers 68 in. diameter by 18 in. wide, fitted with cross-plates. The boiler was of the locomotive type, with wing water-tanks and large bunkers for wood. The single leading wheel was 60 in. diameter, fitted with 5-ft. bearing springs. The main axle rested on 6-in. indiarubber blocks. The weight, in running order, was 14 tons, of which 10 tons was supported by the drivers.

In 1867, it was demonstrated that the indiarubber-wheel engines constructed by R. W. Thomson possessed great tractive power, and therefore that they could be applied to the haulage of heavy loads. On steep inclines of pavement and macadam, small engines of only 6 tons, or 7 tons, readily drew loads that a powerful rigid-wheel engine could hardly have moved. The indiarubber wheels also, from their great bearing surface, enabled the engine to pass easily over soft ground. A 6-ton engine took a load of 10 tons up an incline of 1 in 9, 20 tons up an incline of 1 in 20, and by itself ascended a grass slope of 1 in $4\frac{1}{2}$. A 7-ton engine, with $5\frac{1}{2}$ tons on the drivers, was tested by drawing a dead weight over a pulley. On good ground it gave a pull of 63 cwt., with an adhesion coefficient of ·576, and on a less favourable surface, a pull of 51 cwt. with an adhesion coefficient of ·466.

One of Thomson's engines, with double cylinders, 6 in. diameter and 10 in. stroke, gears of 7 to 1, and 14·6 to 1 respectively, and 60 in. driving wheels, carrying 5 tons, was, on many different occasions, carefully tested with Tennant's road locomotive. As the latter had twice the weight on the drivers when compared with that on the indiarubber wheels, an excellent opportunity was afforded for proving the coefficient of adhesion between rigid tires and elastic tires. Tennant's engine had 10 tons, and Thomson's engine 5 tons, on the driving wheels. On a dry and dusty macadam incline of 1 in 12, Tennant's engine took a gross load of 17 tons, giving a coefficient of adhesion of ·32, and Thomson's engine took the same load of 17 tons, with a coefficient of ·499. Again, on a dry macadam incline of 1 in 25, Tennant's engine took 34 tons, with a coefficient of ·3, while Thomson's engine also took 34 tons, with a coefficient of ·5. These two figures, 3 and 5, very nearly represent the comparative value of indiarubber tires and of smooth iron tires on ordinary macadam. In the trial each engine took the same load, but Tennant's engine, from its superior boiler power, readily ran twice as fast as its smaller competitor, the pot boiler of which would only keep steam for the slowest speed.

1917.





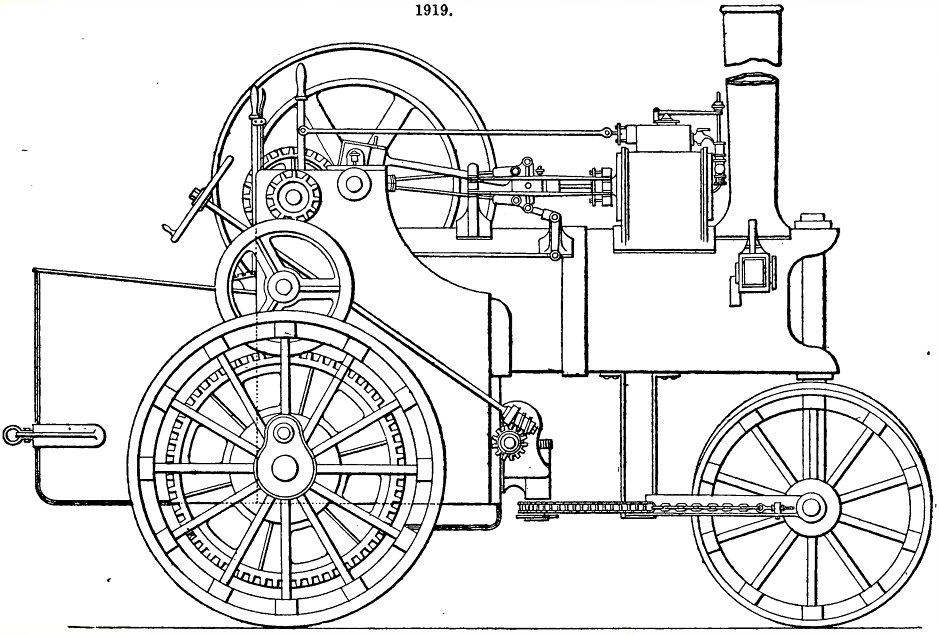
1918.

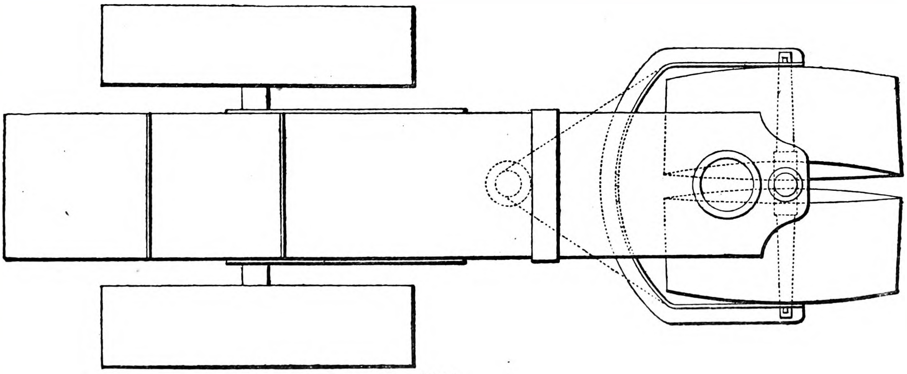
A 10 horse-power goods engine, with 10-in. cylinder and 12-in. stroke, and with driving wheels, 6 ft. diameter and 18 in. broad, manufactured by Aveling and Porter, of Rochester, made the most successful run, in point of consumption of fuel, in the trials of traction engines between Wolverhampton and Stafford, in 1871. The useful load drawn amounted to 15 tons; the distance run was 16 miles; the time occupied, exclusive of stoppages, was 4 hours 48 minutes; and the amount of coal consumed was 2·85 lb. a useful ton of load a mile.

Some further experiments were made at Orange, United States, in the autumn of 1872, with the object of testing the capabilities of road locomotives, and their commercial value, in comparison with horse traction. The engine selected for these trials was one of 6 horse-power, by Aveling and Porter, of which the following are the principal dimensions: cylinder, 7¾ in. diameter, stroke, 10 in.; diameter of driving wheels, 5 ft.; breadth of tire, 10 in.; total weight of engine, 5 tons 4 cwt., of which, 4 tons 10 cwt. were upon the drivers; the wheels were of wrought iron, and were fitted on their periphery with strips of iron laid diagonally across the face. These experiments were conducted by R. H. Thurston, who gives an interesting account of them in a paper read before the Polytechnic Club of the American Institute. He sums up his remarks with the following comparison between haulage by horse and by steam power;—

"The expense account when doing heavy work on the common road, under the described conditions, by steam power, is less than 25 per cent. of the average cost of horse power, as deduced from the total expense of such power in New York State; while, if we take for comparison the lowest estimate that we can find data for, in our whole country, we still find the cost of steam power to be but 29 per cent. of the expense of horses.

1919.





1920.

"We may state the fact in another way. A steam traction engine, capable of doing the work of 25 horses, may be purchased and worked at as little expense as a team of 6 or 8 horses."

One of the most careful and elaborate experiments ever recorded with traction engines, was carried out in 1866, under the direction of Tresca, with one of Aveling and Porter's 10 horse-power traction engines of the following dimensions: cylinder, 11 in. diameter; stroke, 14 in.; diameter of the driving wheels, $6\frac{1}{2}$ ft., with cast-iron rims. The power of the engine was transmitted to the wheel, by means of a pitched chain, in the ratio of 1 to 20 for slow speed, and 1 to 14 for fast speed. The total weight of the engine, when loaded with coals and water, was $17\frac{1}{2}$ tons, or $14\frac{3}{4}$ tons without coals and water. Tresca sums up his report as follows;—

The engine drew, in a regular manner, upon a good road slightly undulating, a total load of 59 tons. The coefficient of traction may be approximately estimated at $\frac{1}{40}$, which would bring the mean strain to nearly $39\frac{1}{2}$ cwt. taking into account the weight of the locomotive. This mean effort, developed at a speed of 3·54 feet a second, brings the valuation of effective work to 15,623 foot pounds a second, or to 27·61 horse-power. This figure will appear high if it be compared with the consumption of fuel, which was 3 cwt. 2 qr. 13 lb. in 3 hours and 3 minutes, say 132·25 lb. an hour of actual travelling. This consumption represents only 4·40 lb. of coal a horse-power and an hour.

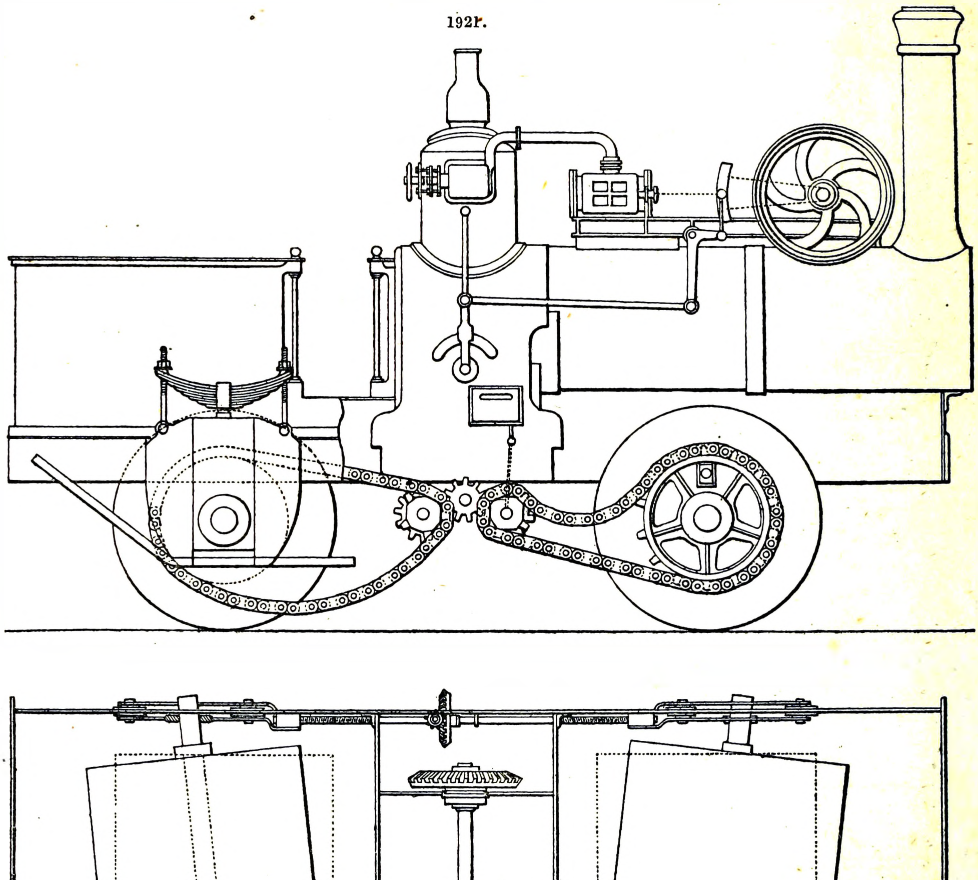
The corresponding consumption of water is not less than 132·22 gallons an hour of actual travelling.

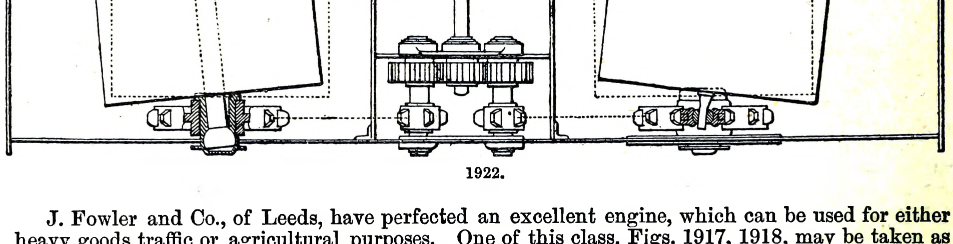
The coefficient of adherence may be estimated on the road gone over at 0·3 of the adherent weight. The adherence resulting therefrom was only necessary for the working of the engine up inclines of 1 in 33 to 1 in 30, and at starting.

The load of 59 tons which the engine drew on level ground is not the limit of what it can draw under these conditions.

The speed of 2·48 miles an hour appears suitable for traffic of this nature, and renders the manœuvres so easy that the train is well managed by a superintendent, an engine-driver, and an assistant solely employed to guide the steering-wheel in front.

1921.





1922.

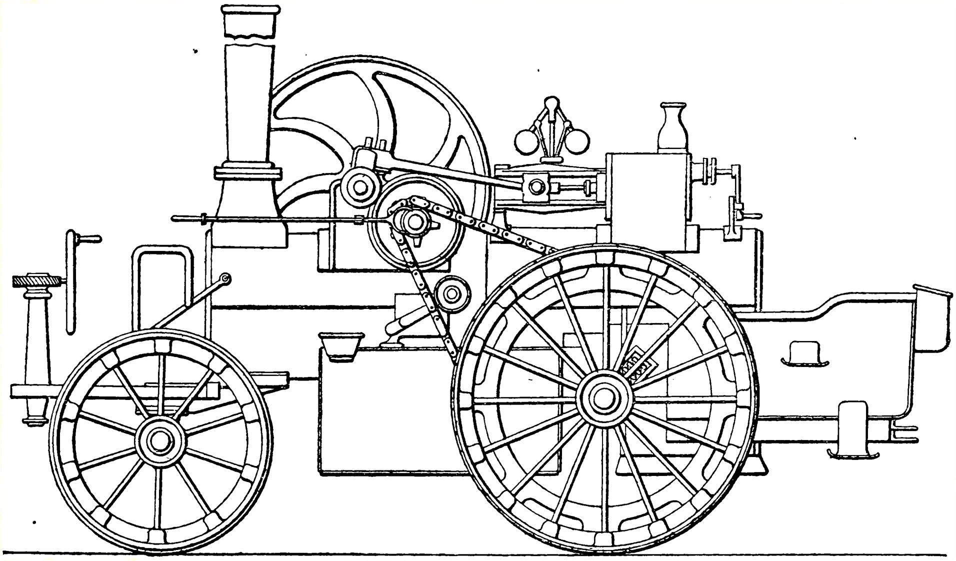
J. Fowler and Co., of Leeds, have perfected an excellent engine, which can be used for either heavy goods traffic or agricultural purposes. One of this class, Figs. 1917, 1918, may be taken as the type of many now in use. The cylinder, 9 in. diameter, 12 in. stroke, is placed on the top of the boiler, which is of the usual locomotive type, with 7·17 sq. ft. of grate surface, and twenty-nine tubes of 2½ in. diameter. The crank shaft is carried on plates riveted to the sides of the fire-box. This forms a compact arrangement. The gearing for transmitting the power of the engine to the driving wheels, at the rate of 1½ mile an hour and 3 miles an hour respectively, is of cast steel, and, together with the working parts of the engine, is enclosed, so as to prevent the noise and motion of the engine frightening horses. A compensating gear, enabling the engine to turn sharp corners, is inserted between the main axle and the driving wheels. The driving wheels are 66 in. diameter and 16 in. wide, fitted with indiarubber tires, and Greig and Aveling's shoes, but the same engine may be used with wrought-iron tires if desired.

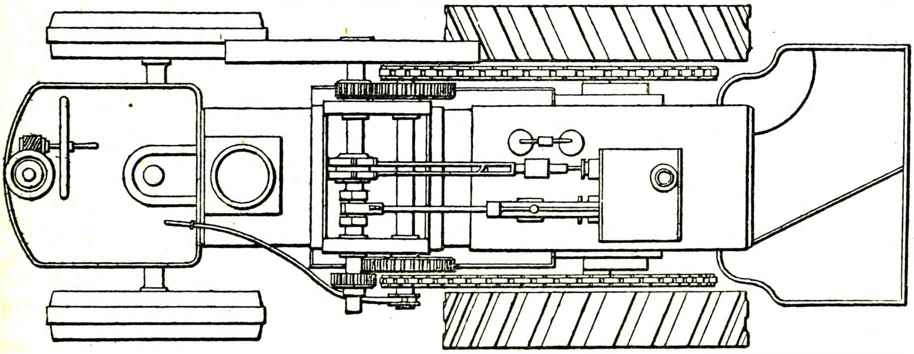
With respect to the advantages of steam road rollers, Aveling states that the road being made for the traffic, and not by the traffic, material is saved; the stones, instead of being left loosely upon the surface to encounter the grinding lateral pressure of the wheels, are forced by direct vertical pressure into the soft bed prepared for them, along with a binding material that fills up the interstices, and affording support for the stones, keeps them in position with one surface only exposed to the abrading action of the wheels. The whole coating is consolidated, and there remains a surface hard and smooth enough to resist the disintegrating action of rain or frost.

The steam roller, by reason of its weight, will consolidate and prepare for traffic newly laid macadam at the rate of 2000 sq. yds. a day, and by reason of its motive power, can work this greater weight for one-quarter the cost of the horse machine. Not only at the same time are the loose stones not torn up, but the heavier roller has the effect of turning down the sharp edges of the stones and leaving their flat sides uppermost, bedding them together in the road, so as to make a solid level surface.

The sizes most in use are those weighing about 15 tons and 20 tons, with driving wheels respectively 5 ft. and 5½ ft. diameter.

1923.



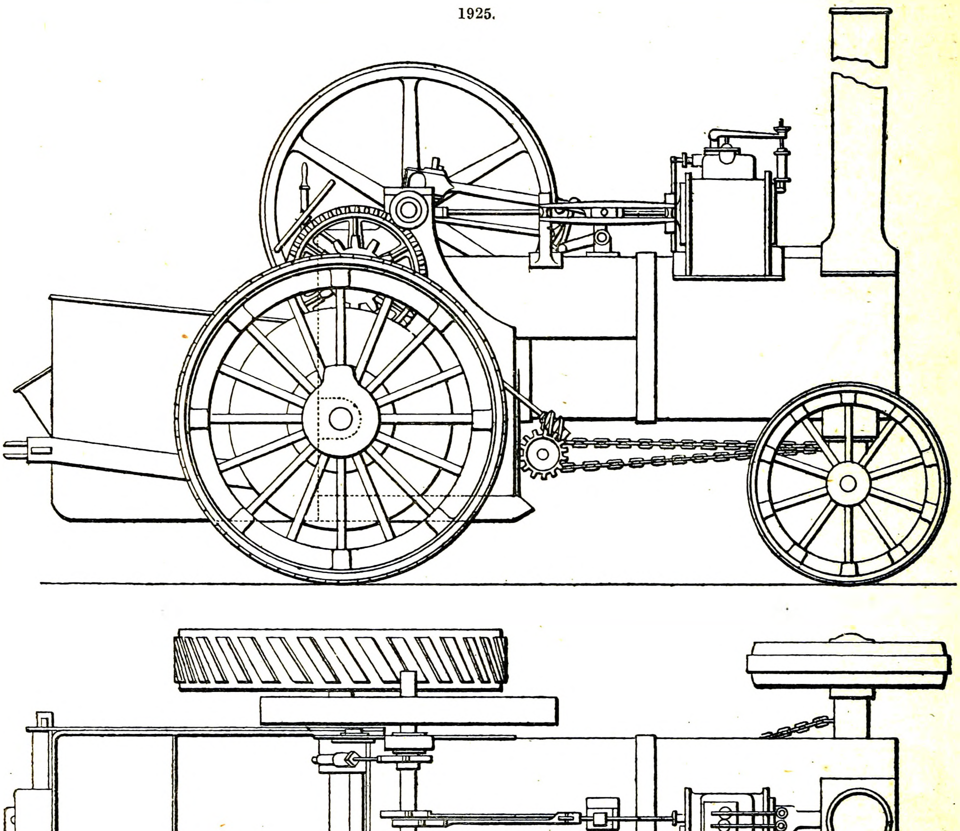


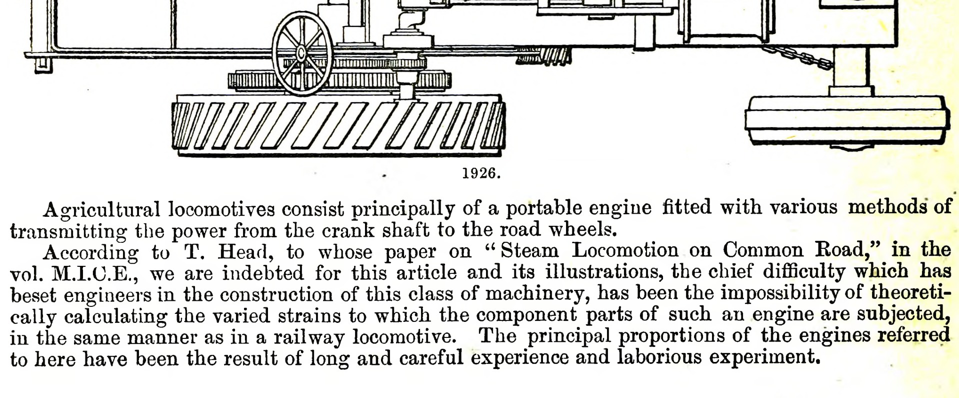
1924.

Aveling's road roller, Figs. 1919, 1920, somewhat resembles one of his traction engines, with the driving wheels converted into rollers, and the space between them covered by a pair of front rollers which also act as steering wheels. These front rollers are made conical, or dished, in order that on the ground line they may be close together; while above their axle there is a space for a vertical shaft, serving as a support for the front of the boiler. To the extremities of this axle a forked, or saddle piece is attached, to act as a guide for the steering chains; and these chains pass rearwards to a transverse roller, which is acted upon by a worm and pinion connected with the steerman's wheel. By keeping the driving wheels behind, instead of in front, as in the engines previously described, the greatest bite is obtained in ascending inclines and going over soft places. Besides being capable of hauling trucks, this engine is furnished with a fly-wheel, and can be used for driving a stone breaker, or any other machinery connected with road making. Its weight is about 8 tons, and the nominal power of the engine is 5 horse-power.

In Paris the Gellerat system of steam road roller has been employed, Figs. 1921, 1922. This engine has been manufactured by Manning, Wardle, and Co., of Leeds. It has two cylinders, each 7 in. diameter, and 11 in. stroke, mounted on a locomotive boiler with 285 sq. ft. of heating surface. The rollers are 3 ft. 11 in. diameter and 4 ft. 7 in. wide, and are connected to the engine by means of pitched chains. The large-sized engines weigh 30 tons, and the small-sized engines weigh 15 tons. On the side of the engine where the attachment is made with the crank shaft, the axles turn in radial boxes, fixed to horn plates, similar to an ordinary locomotive; whilst on the other side, the axle-boxes are free to move backwards and forwards, sliding on the frame of the engine, and connected together by a rod with a male and female screw, worked from the foot plate by a vertical shaft connected by bevel wheels with the steersman's handle. When the engine moves in a straight line the axles are kept parallel; but when necessary to turn a corner, the centres on one side are drawn together, and consequently, the rollers act like a double steering wheel, turning the engine in a very small space.

1925.





1926.

Agricultural locomotives consist principally of a portable engine fitted with various methods of transmitting the power from the crank shaft to the road wheels.

According to T. Head, to whose paper on "Steam Locomotion on Common Road," in the vol. M.I.C.E., we are indebted for this article and its illustrations, the chief difficulty which has beset engineers in the construction of this class of machinery, has been the impossibility of theoretically calculating the varied strains to which the component parts of such an engine are subjected, in the same manner as in a railway locomotive. The principal proportions of the engines referred to here have been the result of long and careful experience and laborious experiment.

The following data, respecting the cost of power in steam ploughing, was deduced from the various experiments and trials which were carried out at Wolverhampton in 1871;—

The average consumption of coal = 161 lb. an acre.
" " water = 115 gallons an acre.
" " oil and tallow = 5·1 oz. an acre.
" " water a lb. of coal = 7·2 lb.
" " coal a mean I.H.P. an hour = 7·1 lb.
" weight of earth moved a lb. of coal = 9·3 tons.

Figs. 1923 and 1924 represent C. Burrell's farm locomotive. The boiler is multitubular, of the usual locomotive type; the cylinder is 9 in. diam. and 12 in. stroke, and the motion of the crank shaft is transmitted to the driving wheels, 5 ft. 6 in. diam., by means of two pitched chains, one on each side of the engine; thus relieving the main axle of the undue torsion which is liable to occur when only one wheel is coupled. Each chain pinion is provided with a clutch, so that the driver may disconnect either wheel when turning corners. The hinder part of the engine is mounted upon volute springs, set at an angle, so as not to interfere with the movement of the chains, and it has been found in practice that the use of springs diminishes, to a great extent, the wear and tear of these engines. The driving wheels are made with wrought-iron spokes and cast-iron naves and rims, the latter partially covered with wrought-iron diagonal plates.

T. Aveling, well known as an agricultural locomotive manufacturer, exhibited his traction engine for the first time at the Royal Agricultural Society's meeting at Canterbury in 1860, but it was not until the year 1871, that the Society considered this class of machinery sufficiently useful in agricultural operations to be placed on the competitive list of prizes.

In the first engines designed by Aveling, the transmission between the crank shaft and road wheels was effected by means of a pitched chain, and the engine was steered by a fifth wheel in the form of a disc, placed at the end of a wrought frame fixed to the fore axle.

Figs. 1925 and 1926 represent one of Aveling and Porter's 8-H.P. agricultural locomotives. The general design outwardly resembles some of the engines already described, but care has been taken in the manufacture to make every part as light as possible, consistently with the work it has to perform. The boiler is locomotive, with 4·3 square feet of fire-grate surface; 30 tubes 2½ in. diam.; total heating surface, 130 sq. ft. The cylinder is 9 in. diam., and 12 in. stroke and is placed at the forward part of the boiler surrounded by a dome, from whence the steam is taken to the slide valve. The motion is transmitted by gearing, the toothed wheels being made of malleable iron to prevent breakage. An arrangement is provided for disconnecting the crank shaft from the train of wheels, so that the power of the engine may be used for driving machinery used on a farm, through the medium of a fly-wheel placed on the side of the crank shaft opposite to the wheels. The main plummer blocks are supported on the outside plates of the fire-box, which are carried up to the requisite height. This arrangement combines lightness with strength, avoiding many of the breakages which used to occur with the cast-iron saddles formerly used. The driving wheels are 66 in. diam., 12 in. wide, and may either be constructed of cast iron, wrought iron with diagonal strips, or with indiarubber springs on Adams' patent.

These engines, as well as those of Fowler, are provided with a compensating or differential gear, similar to that attached to the wheel, Fig. 1912, for transmitting the motion of the crank shaft to the driving wheels, thereby enabling the engine to turn sharp corners without the use of disengaging-clutches.

One wheel turns freely on the nave, whilst the other on the opposite side is keyed fast on to the axle. A bevel wheel is bolted to the nave of the wheel, and one of equal size is keyed fast to the shaft. Between these the spur gear revolves, driven by the pinion on the crank shaft, and it carries in two recesses a couple of small bevel pinions, both gearing into each of the larger bevel wheels.

The resistances being equal on both wheels, if the spur gear is turned, it will carry with it both driving wheels at the same time with equal angular velocities, the effort exerted by the engine being equal on both wheels at all times; but in turning a corner, the greater resistance on the inside wheel retards it, while the outer wheel necessarily moves more rapidly over its longer path, and, as the engine exerts the same force on both wheels, the work done is distributed unequally between them through the revolving bevel pinions, without either wheel being necessarily slipped or disengaged.

ROCK DRILL.

The labour of boring shot-holes by hand is extremely tedious; this has led to the invention of various machines for expediting the work, and thereby reducing both delay and expenditure.

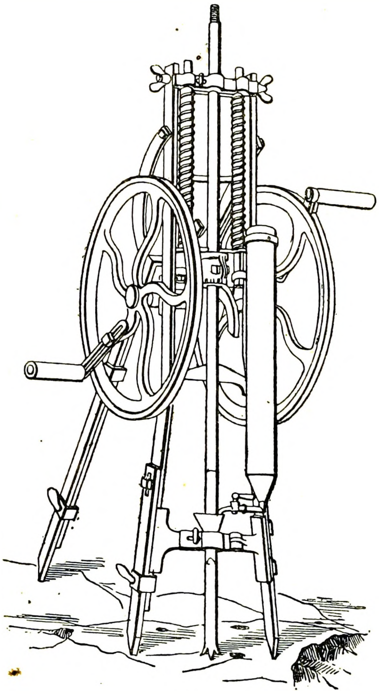
The simplest forms of rock drill is that of the screw auger, turned by some device similar to a ratchet brace; but this is only available for use in comparatively soft ground, such as chalk and some varieties of coal. A machine of this kind, termed a perforator, has done good service in soft ground, but it is obviously useless in very hard rock where a percussive action is necessary, and to effect this is the object of the machines, Figs. 1927 to 1930. Fig. 1027 is of a rock drill devised by W. Weaver, of Pennsylvania; it consists of a frame of bar iron which can be readily taken to pieces for transport. The boring bit has a shoulder piece clamped on to the centre, and this is kept down by means of springs arranged on either side; a light shaft runs through the machine, to which cams are attached, and this also carries a pair of fly-wheels and handles. When these are turned, the cams alternately raise and release the bit against and from the pressure of the springs, thereby producing a succession of short powerful blows; a small cylinder attached to the frame of the machine contains water which is passed through the cock down to the bit, and assists the operation of boring.

A great advance upon this is the drill of T. B. Jordan, London.

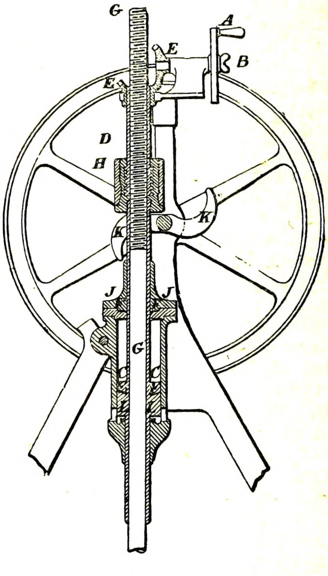
Fig. 1928 is a section of the machine; it is composed of an air-tight cylinder C, in which the piston L is forced up twice in every revolution of the fly-wheels by the cams K K. This action of the cam compresses the air in the cylinder, which forces the piston down when released, and gives the blow, and at the same time feeds the tool forward, by causing it to turn in the brass nut D, screwed to fit the upper portion of the drill bar. It will be seen, therefore, that, as the cams while lifting the piston turn the drill bar G, it must feed forward in proportion to the amount of stop put upon the nut D, by the brake B acting upon the mitre wheels E in connection with it. The three actions absolutely necessary in rock drilling, heavy blow, variable feed forward of the drill, and constant turning of the latter in the bottom of the hole, are thus obtained by simple means, and without valve, tappet, or any complicated arrangement of parts. The cylinder is made tight by placing discs of leather in the upper gland and piston, so that the same air is compressed for each blow.

The air in the cylinder can be compressed to any extent, and with the power of two men, 150 blows of about 130 to 160 lb. each a minute can be delivered by these machines.

1927.



1928.



They are made in various forms to suit the different conditions under which they have to work; but the power-cylinder and the drill bar, as well as all the parts requisite to give motion to the tool, are of the same construction in each case.

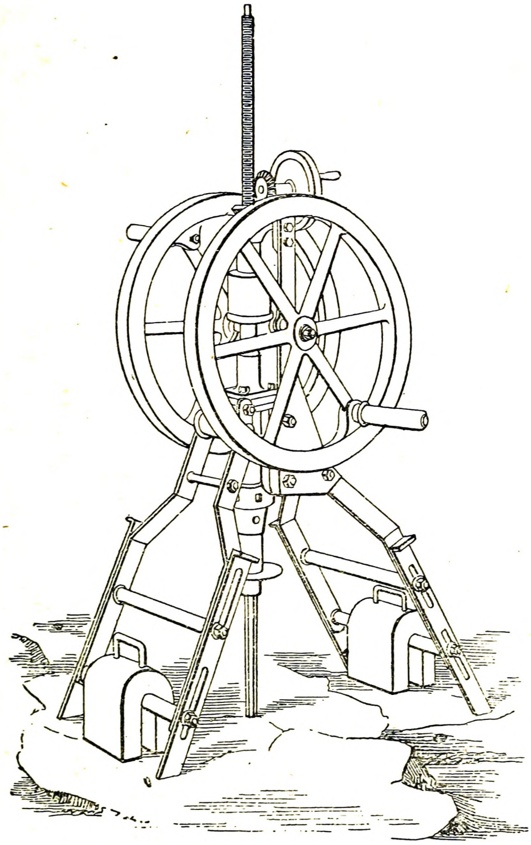
In Fig. 1929, Jordan's drill is mounted on a carriage, and adapted for boring holes in a vertical or slightly inclined position, its most effective arrangement.

Fig. 1930 is an illustration of a new form of rock drill constructed by Barlow and Co., of Manchester. The machine consists of a light stand supporting guides which can be adjusted to various inclinations. The boring tool is not connected to the hammer, but rests on the rock, being merely guided by the collars, through which it passes, and which ensure its being kept parallel with the hole. One of the guide collars has an intermittent rotary motion given to it by a ratchet, this causing the tool to be partially rotated after each blow.

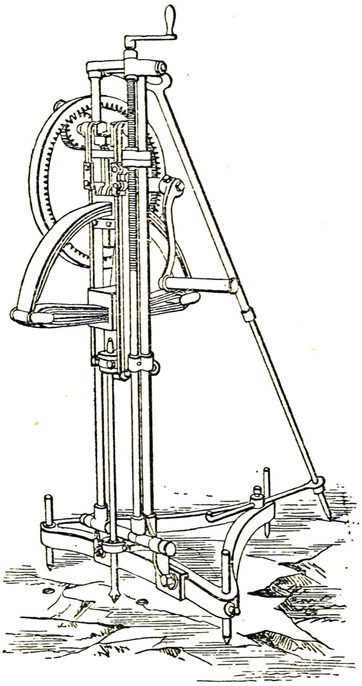
The tool is struck rapidly by a steel-faced hammer, worked by a crank through the medium of a spring. The throw of the crank is 1¼ in., but when in full work the hammer under the action of the spring moves about double the stroke due to this throw, a speed of 40 revolutions a minute of the handle causing 212 blows a minute of about 5 in. fall to be struck by the hammer. The machine is simple, and readily set to work.

None of these afford, however, anything like the result that can be obtained by the direct application of power to driving the drills, this has been effected in numerous machines. Their use indeed forms the most remarkable advance which has been made in the practice of mining, since not only is the miner relieved from the labour of boring, but the speed with which the shot-holes may be bored is increased one hundred fold; this gain of speed offers many practical advantages. The ability to sink a shaft or to drive a heading rapidly may ensure the success of an undertaking, and save large sums of money, and in all cases it allows the time spent in preparatory work to be materially shortened. Machine drills penetrate rock in the same way as the ordinary hand drills, namely, by means of a percussive action. The cutting tool is in most cases attached directly to the piston rod, with which it consequently reciprocates. Thus the piston with its rod is made to constitute a portion of the cutting tool, and the blow is then given by the direct action of the steam, or the compressed air, upon the tool. As no work is done upon the rock by the back stroke of the piston, the area of the forward side is reduced to the dimensions necessary only to lift the piston, and to overcome the resistance due to the friction of the tool in the bore-hole. The piston is made to admit steam or air into the cylinder and to cut off the supply, and to open the exhaust as required by means of tappet valves, or other suitable devices; and provision is made to allow, within certain limits, a variation in the length of the stroke. During a portion of the stroke, means are brought into action to cause the piston to rotate to some extent, for the purposes that have been already explained. To keep the cutting edge of the tool up to its work, the whole machine is moved forward as the rock is cut away. This forward or feed motion is usually given by hand, but in some cases it is communicated automatically.

1929.



1930.



The foregoing is a general description of the construction and mode of action of percussive rock-drills. The numerous varieties now in use differ from each other rather in the details of their construction than in the principles of their action, and the importance of the difference is, of course, dependent upon that of the details. It is but just to remark here that the first really practical solution of the rock-drilling problem is due to M. Sounneiller, whose machine was employed in excavating the Mont Cenis tunnel.

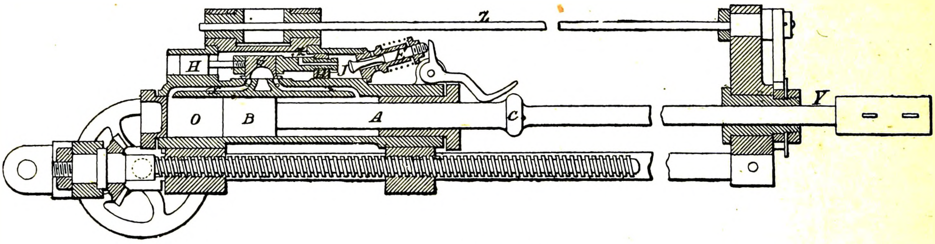
The Dubois-François rock-drill, Fig. 1931, is of a type already discarded, but it was one of the first introduced and has done good service.

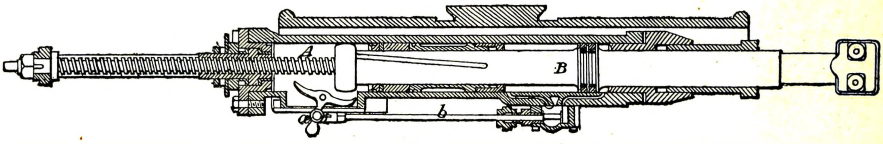
The piston B reciprocates in a cylinder O. The rod A of this piston is of comparatively large dimensions, and is provided at its lower extremity with an enlarged section pierced to receive the cutting tool. The valve gear is altogether of a special character. An ordinary slide valve G is connected to two slide pistons H and H′, each moving in a cylinder provided for it. The piston H′ has a larger surface area than the piston H. When the compressed air enters the valve chest, it exerts a pressure upon both pistons, which tends to force them in contrary directions. But as the area of H′ is greater than that of H, the pistons, being connected by their rods and the valve, move forward. This motion opens the port *x*, air is admitted above the main piston B, and the drill-bit is driven against the rock. H′ is, however, pierced by a small passage *i i*, which allows the compressed air to pass to the other side of it in J, by which means equilibrium is restored upon the two surfaces, and when established, the action of this piston is destroyed, and, consequently, the pressure acting upon the other piston H, forces the pistons in the contrary direction. This motion opens the port *z*, air enters below the piston B, and the drill-bit is withdrawn from the rock. To cause this action of the pistons to be repeated, an annular projection C, upon the rod A, comes in contact during the back stroke with a lever, which, being raised, opens the valve E. The air in the space J escapes, and the equilibrium of the piston H′ is thereby destroyed.

It will be seen that the action of this valve gear throws the motive force suddenly upon the percussion piston for the forward or working stroke, while it effects the return stroke in a less violent manner. The size of the air passage through the valve piston H' is a matter of importance. To determine the most suitable proportions, many experiments were needed. If this passage were too large, equilibrium would be established too soon, and a consequent jerky motion would be produced in the percussion piston; if it were too small, the motion of the latter would be too slow and irregular.

The rotation of the drill-bit is obtained by the alternate action of two small pistons not shown. These pistons are single acting, and receive compressed air through opening upon the ports of the main piston B. The alternating action thus obtained is transmitted by a rigid rod Z to a ratchet wheel Y, fixed up the rod A, in the fore part of the machine. The feed motion is accomplished by means of a screw, turned by a handwheel. The principal dimensions of the machine are;—Total length, 7 ft. 2 in.; weight, 484 lb.; diameter of the cylinder, 2½ in.; diameter of the piston rod, 1½ in.; maximum stroke, 7¾ in.; weight of the striking mass, including 8-lb. borer-bit, 68 lb.; length of feed, 31½ in.

1931.





1932.

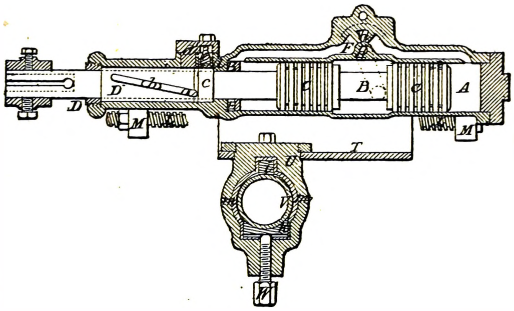
This machine has an unnecessary degree of complexity, occasioned by the presence of no less than five pistons. Those which actuate the rotating gear also appear to be too much exposed to injury from dirt and gritty water. The ratchet gear being exposed, is liable to injury from blows and strains otherwise caused, and to be impeded in its action by grit. It is really only serviceable for horizontal holes and has almost gone out of use.

The Burleigh rock-drill, Fig. 1932, consists of a cylinder A, a piston B, with its rods, and a valve gear *a*, *b*. Both the back and forward piston-rods pass through stuffing boxes in the cylinder; to the forward rod the borer-bit is fixed; the back rod, which is made smaller in diameter than the forward rod, to give a larger piston area on that side, terminates in an annular protuberance. This is intended to strike alternately during its reciprocating motion the back and forward arms of the tappet lever *a*, to which the rod of the slide valve is attached. The rocking motion of the lever thus produced communicates the requisite reciprocating motion to the valve, and by this means the desired action of the piston is ensured. To effect the rotary motion of the latter, the back piston-rod is provided with a spiral feather, which works in a corresponding groove in a cylindrical piece fitting into the back portion of the cylinder. This cylindrical piece is provided on the outside with teeth, thereby forming a kind of ratchet wheel. A detent held up by a spring prevents the piece from turning in one direction, but allows it to revolve freely in the contrary. By this means the piston is made to turn partially round during the back stroke; but during the forward stroke the piston turns the cylindrical piece before described, the motion of which in that direction is unrestrained by the detent. The forward motion of the cylinder, or feed motion, is affected automatically by means of the screw, actuated by suitable mechanism. This feed-screw passes through a gallows-frame affixed to the back end of the bed-plate and again through a feed-nut in the cylinder. The end of the piston is drilled out, in order that the feed-screw may not be struck by the former during its oscillations. The feed-nut is secured between two collars in a manner to allow of easy revolution, and its outer edge is cut into a ratchet, into which works a pawl actuated by the piston. The turning of the nut by this means upon the fixed screw moves the cylinder forward. The mechanism by which this is accomplished is shown in Fig. 1932. When the tool has penetrated the rock, and the piston consequently advanced nearer the front cylinder cover, the protuberance upon the back piston-rod strikes against a catch, and thereby releases a lever. The latter is then forced inwards by a spring, so as to be struck by the head of the piston at the return stroke, by which means it is again restored to its original position. The other end of the lever being connected to the pawl before mentioned, the feed-nut is turned by the extent of one tooth. This action is repeated as the penetration of the tool progresses. Frequently the automatic feed gear is omitted from the construction, and the necessary motion communicated by hand.

The principal dimensions of this machine are the following;—Total length, 51 in.; weight 166 lb.; diamenter of cylinder, 2¾ in.; diameter of back piston-rod, 1¾ in.; diameter of forward piston-rod, $2\frac{1}{4}$ in.; maximum length of stroke, $4\frac{1}{2}$ in.; weight of the striking mass, including 8-lb. borer-bit, 34 lb.; length of feed, 22 in. In the Burleigh machine there exists considerable complication of parts, and many are of a fragile character. The striking gear by which the valve is actuated is liable to rapid wear and frequent derangement. Also its exposed situation on the outside of the machine must tend to favour the occurrence of such results. The mechanism for producing the automatic feed is delicate and somewhat complicated.

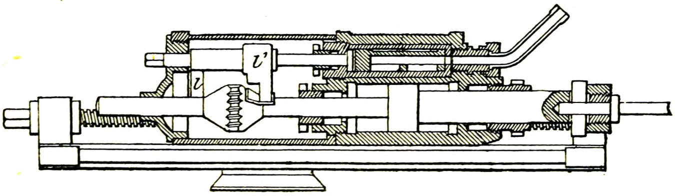
The Kainotomon rock-drill, Fig. 1933, is an improvement upon the Burleigh. It has a cylinder A, a piston and piston rod B C, and the valve gear at F. The valve is pivoted at H; it has an arm G, the projection on which is struck by the two pistons alternately during the reciprocating motion of the latter; by this means the requisite motion is communicated to the valve. The motor fluid is admitted through *k* and the ports *g g*, and exhausted through the port *h*. The rotation of the tool is effected by the same means in the Kainotomon as in the Burleigh machine, the position only of the parts being changed. The piston rod passes through a cylindrical piece D called the rotation tube, placed in the neck of the cylinder, and held in position by the washer D. This tube is provided with a spiral slot *a*, in which works a projection *b* in the piston rod. On the upper end of the tube D′ are ratchet teeth *c*, into which the pawl *d* is forced by means of a spring *e*, the pawl and spring being held in position by a gun-metal cap. The teeth and pawl are arranged so as to compel the piston rod to rotate during the backward stroke, and to allow it to turn freely during the forward stroke. In the forward end of the cylinder is an elastic packing ring E′, which is held in position by a steel washer E; this serves as a buffer to mitigate the destructive effects of the blow should the piston strike against the forward end of the cylinder. The feed motion is communicated by hand, by means of the feed-screw L, which runs parallel with the cylinder, and is held by the lugs M M cast upon the cylinder. The machine slides in the jacket T. The universal clamp U deserves special attention, as it allows the machine to be turned in any direction, and to be fixed upon the cylindrical bar V, by simply tightening the set screw W, which acts upon the gripping plates *i* and *k*, and the washer *m*.

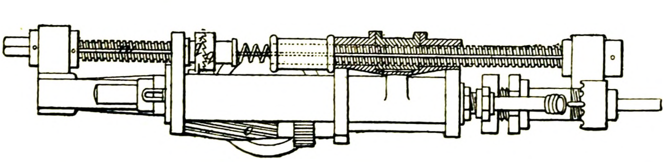
1933.



The following are the principal dimensions of the machine;—Total length, 36 in.; weight, 205 lb.; diameter of cylinder, $3\frac{1}{2}$ in.; diameter of piston rod, 2 in.; maximum length of stroke, $4\frac{3}{4}$ in.; weight of the striking mass, including 8-lb. borer-bit, 53 lb.; length of feed, 18 in. The valve in the Kainotomon drill is very sensitive to rough treatment, and in ordinary work constantly out of order.

1934.





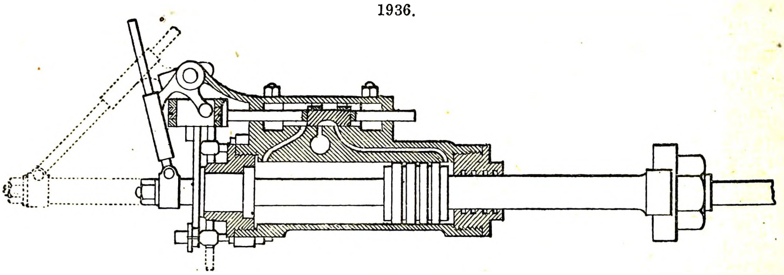
1935.

The characteristic peculiarities of the McKean machine drill are shown in Figs. 1934, 1935. Besides the anterior piston-rod to which the tool is attached, there is a posterior rod which passes through the back end of the cylinder, and is prolonged through the valve and feed-gear chamber situate behind the cylinder. Upon this prolongation of the rod is an enlargement of an ovoid form, as in Fig. 1934. During the reciprocating motion of the piston, this enlarged piston strikes alternately the arms *l* and *l′* which hang upon the opposite sides of the piston rod. By this means an oscillating motion is produced in the rod upon which the arms are fixed, which is communicated to the valve; the form and action of which will be understood from Fig, 1934. To give the requisite rotary motion to the tool, the enlarged portion of the piston rod is provided with spiral teeth, which gear into corresponding spiral teeth on a rotary cam-spindle *o*, provided with a ratchet wheel which is held by a pawl, so that the cam may turn only in one direction, namely, during the backward stroke of the piston. To produce the feed motion, a ratchet wheel *q* is placed loosely upon the feed-screw *n*. This wheel is connected by means of the arm *q′* with the arm or lever *l′* upon the valve rod, as in Fig. 1935, and by this means the oscillating motion of the latter is communicated to the wheel. This motion is transmitted to a crown ratchet-wheel *p*, which is held up to the wheel *q* by a spring, and by means of which the cylinder is moved forward upon the feed-screw *n*. Such are the general and distinctive features of the McKean drill as applied in the St. Gothard tunnel.

The following are the dimensions of this drill;—Total length, 38 in.; weight, 150 lb.; diameter of cylinder, 3 in.; diameter of anterior piston-rod, 2 in.; diameter of posterior piston-rod 1¼ in.; maximum length of stroke, 4 in.; weight of the striking mass, including 8-lb. borer-bit, 32 lb.; length of feed, 12 in.

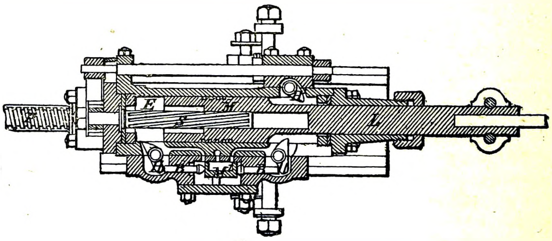
Fig. 1936 is a section of the Sach's drill. As the details of construction are therein clearly shown, a general description of the action will be sufficient to make it understood. The slide valve is of the ordinary character, and the mode of admitting, cutting off, and exhausting the motor fluid precisely the same as in an ordinary steam engine. The valve is worked by a bell-crank lever connected with the piston rod in the manner shown in the drawing. Thus the motion of the valve is wholly dependent upon that of the piston. It will be observed that ample clearance space is provided at each end of the cylinder. To give the requisite rotary motion to the tool, another arm of the rocking lever communicates a reciprocating motion to a rod, to which are fixed two ratchet pawls held up against the teeth of a ratchet wheel upon a cylindrical piece, through which the rod passes at the upper end of the percussion cylinder. This cylindrical piece is provided on the inside with a groove in which a rib upon the rod slides. The action of the pawls causes the wheel to revolve. The feed motion is communicated by hand in the usual manner by means of a screw and crank handle, or wheel, as in the Dubois-François machine, Fig. 1931. This is the mode of feeding adopted in what is known as the low-pressure machine. In the high-pressure machine, which is made of small cylinder dimensions, the feed is made automatic by connecting the mechanism with the rotating gear. The Sach's drill has had extended application in Germany.

1936.



In the Ingersoll rock-drill, Fig. 1937, E is the cylinder, M the piston, and L the piston rod. The valve gear is actuated by the piston through the medium of tappets, and consists of a slide valve M′, two valve rods or spindles B, and two tappet levers H. The action of this valve gear and of the piston needs no description. The rotary motion of the tool is obtained by means of the spirally grooved bar S, recessed into the back end of the piston. A cap screwed into the piston is provided with studs or feathers to run in the grooves of the bar. On the end of the latter is a ratchet wheel, into the teeth of which a pawl is held by a spring. This pawl, as in the case of some of the machines already described, forces the piston to turn during the back stroke, but allows the spiral bar to rotate during the forward stroke. The forward motion of the cylinder, or feed motion, is produced automatically in the following manner;—As the tool penetrates the rock, the piston approaches the forward end of the cylinder, and strikes against a tappet lever H′, which partially rotates the rod R in the manner shown in Fig. 1937. This rod turns, by means of pawls and ratchet teeth, a nut upon the back end of the cylinder, through which nut passes the feed-screw P, as shown at V. The rotation of this nut upon the feed-screw causes the cylinder to advance.

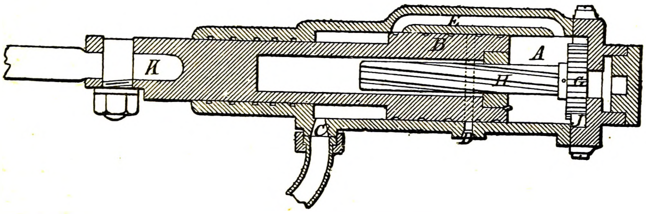
1937.



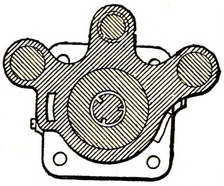
The following are the principal dimensions of this machine;—Total length, 30 in.; weight, 155 lb.; diameter of cylinder, 2¾ in.; diameter of piston rod, 2 in.; maximum length of stroke, 4 in.; weight of the striking mass, including 8-lb. borer-bit, 26 lb.; length of feed, 19 in.

The Darlington rock-drill, Figs. 1938, 1939, consists of only two parts; the cylinder A, Fig. 1938, with its cover, and the piston B, with its rod. The cover, when bolted on, forms a part of the cylinder; the piston rod is cast solid with the piston, and is made sufficiently large at its outer end to receive the tool. These two parts constitute an engine, and with less than one fixed and one moving part, it is obviously impossible to develop power in a machine by the action of an elastic fluid. The piston itself is made to do the work of a valve in the following manner;—The annular space affording the area for pressure on the fore part of the piston, gives a much smaller extent of surface than that afforded by the diameter of the cylinder, Fig. 1938; and it is obvious that, by increasing or diminishing the diameter of the piston rod, the area for pressure on the one side of the piston, may be made to bear any desired proportion to that on the other side. The inlet port C being in constant communication with the interior of the cylinder, the pressure of the fluid is always acting upon the front of the piston; consequently, when there is no pressure upon the other side, the piston will be forced backward in the cylinder. During this backward motion the piston first covers the exhaust port D, and then uncovers the equilibrium port E, by means of which communication is established between the front and back ends of the cylinder, and consequently the fluid made to act on both sides of the piston. The area of the back face of the piston being greater than that of the front face, by the extent occupied by the piston rod, the pressure upon the former first acts to arrest the backward motion of the piston, which, by its considerable weight and high velocity, has acquired a large momentum, and then to produce a forward motion, the propelling force being dependent for its amount upon the difference of area on the two sides of the piston. As the piston passes down, it cuts off the steam from the back part of the cylinder, and opens the exhaust. The length or thickness of the piston is such that the exhaust port D is never open to its front side, but in the forward stroke it is open almost immediately after the equilibrium port is closed, and nearly at the time of striking the blow. It will be observed that the quantity of fluid expended is only that which passes over to the back face of the piston, since that which is used to effect the return stroke is not discharged.

1938.



1939.



The means employed to give a rotary motion to the tool consist of a rifled bar H, having three grooves, and being fitted at its head with a ratchet wheel G′, recessed into the cover of the cylinder. Two detents J J, Fig. 1938, also recessed into the cover, are made to fall into the teeth of the ratchet wheel by spiral springs. These springs may, in case of breakage, be immediately renewed without removing the cover. It will be observed that this arrangement of the wheel and the detents allows the spiral bar H to turn freely in one direction, while it prevents it from turning in the contrary. The spiral bar drops into a long recess in the piston, which is fitted with a steel nut, made to accurately fit the grooves of the spiral. Hence the piston during its instroke is forced to turn upon the bar, but during its outstroke it turns the bar, the latter being free to move in the direction in which the straight outstroke of the piston tends to rotate it. Thus the piston, and with it the tool, assumes a new position after each stroke.

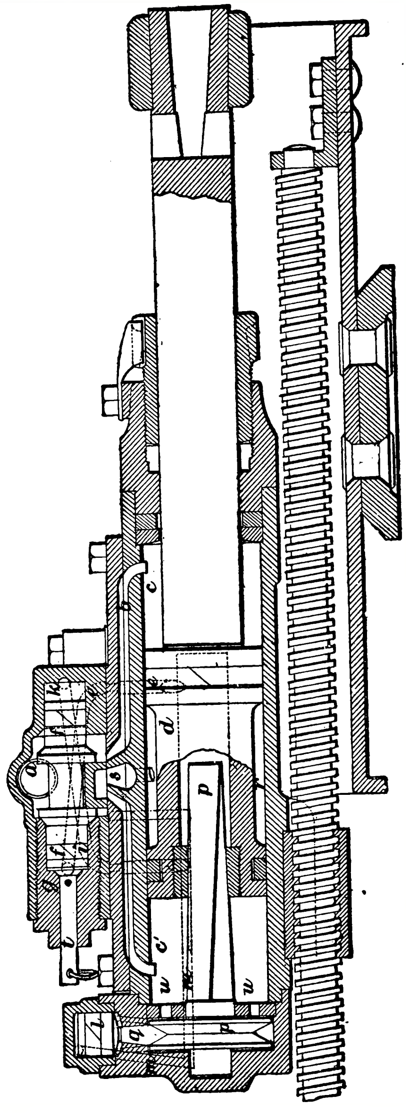
The following are the principal dimensions;—Total length, 36 in.; weight, 100 lb.; diameter of cylinder, 3½ in.; diameter of piston rod, 2½ in.; maximum length of stroke, 4 in.; weight of the striking mass, including 8-lb. borer-bit, 35 lb.; length of feed, 24 in.

For holding the tool, the outer end of the rod is first flattened, to afford a seat for the nut, Fig. 1938. The slot is then cut and fitted tightly with a piece of steel K, forged of the required shape for the clamp, and the holder is afterwards bored to receive the tool while the clamp is in place. This clamp K is then taken out, its fitting eased a little, and its end screwed and fitted with a nut. When returned to its place in the holder, the clamp, in consequence of the clearance, can be easily drawn tight against the tool, by which means it is firmly held in position. The shank of the tool is turned to fit the bottom of the hole, upon which the force of the reaction of the blow is received.

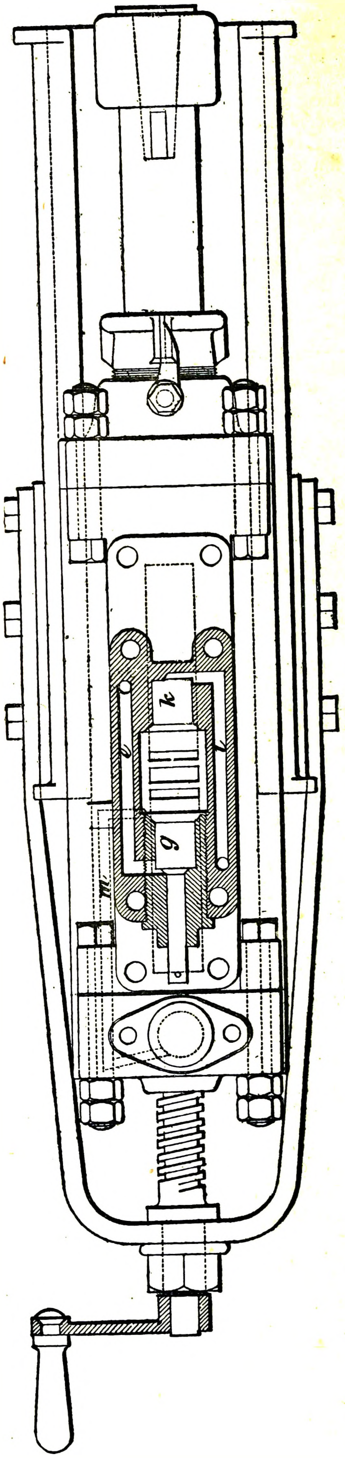
The absence of a valve or striking gear of any kind ensures a high degree of durability, and allows a rapid piston speed to be adopted without risk of injury, whilst as the piston controls its own motion, there is no liability to strike against the cylinder cover.

This drill has been much used both in England and on the Continent, and its employment in many leading mines has contributed materially to solving the difficult problem of increasing the speed of driving levels and sinking shafts by the employment of rock-boring machinery.

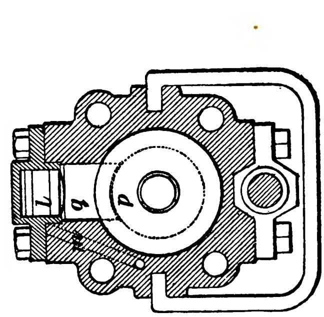
The Schram Rock Drill, Figs. 1940 to 1942, consists of the following simple moving parts;—*d*, the main piston; *f*, the slide piston and slide; *l p q*, the rotating movement with its piston. Fig. 1941 shows a longitudinal section of the machine, and Fig. 1942 a plan with section of the slide box through *g k*. When the piston *d* is in the position shown in Fig. 1941, air, on the cock being opened, enters the cylinder *e* through the port *b*, and pressing on the lower end of the piston *d*, forces it backwards, causing the backward stroke. As soon as the piston *d* has passed the port *e*, the air rushes through that port into the small cylinder *g*, in the slide box. At this moment, when the air presses upon the upper end of the slide piston *f*, the cylinder *k* in the opposite end of the slide box is in communication with the outlet *s* through the port *i* and the circular hollow in the piston rod *r*; consequently the slide piston with the slide is moved downwards, so that the passage *h* is opened for



1941.



1942.



1940.

the admission of air from the slide box, whilst the lower end of the cylinder through the port *b* now communicates with the outlet *s*. The air now entering the cylinder *c'* through the open port *h*, presses on the upper end of the piston, forcing it forward, and thus causing the drill, carried in a socket at the extremity of the piston rod, to strike with the impetus of its own weight and all the power of the compressed air against the rock. As soon as the piston *d* has passed the port *i*, air enters through it into the cylinder *k*. At this moment the cylinder *g* communicates with the outlet *s* through the port *e* and the circular hollow *r* in the piston rod, and the slide piston with the slide is moved back into the same position, as shown in Fig. 1941. Meanwhile the piston *d* has completed its stroke; the cylinder *c'* is, through the passage *h*, in communication with the outlet *s*; and compressed air again rushing through the re-opened passage *b* causes the action just described to be repeated so long as the supply of motive power is kept up.

It is an important feature in this machine that the slide rod *f* is made in the form of a double spindle-valve. By this method of construction it remains in position without any recoil until the piston *d* has made the greater part of its stroke.

As in some varieties of rock it happens that the drill often sticks fast, there is a reversing rod *t* to suddenly reverse the slide, and thus pull the drill out of the hole.

With careless workmen it would frequently happen that the piston would strike against the lower cylinder cover, therefore there is an air cushion at the lower end of the cylinder. In addition to this there are an iron ring and an indiarubber washer, exchanged for one of wrought iron when steam is used, with the object of moderating the violence of the shock such blows, inadvertently permitted, would cause.

In order that the hole drilled be perfectly round, it is necessary that the cutting tool should partially rotate at each backward stroke, so that its cutting edge shall every time strike the rock in a fresh place; but in order not to lose any power it must always make its forward stroke without rotating. For this purpose a twisted bar is employed, connected with a grooved disc *p*, and a brake *q* acted upon by a small piston *l*. Communicating from the slide box with the main cylinder is a small port *m*, by means of which the compressed air exerts a constant pressure upon the upper end of the piston *l*. When the main piston *d* makes its backward stroke, the cylinder *c'* is in communication with the outlet, and consequently there is no pressure on the lower end of the piston *l*. The constant pressure on the upper end of this piston, therefore, now presses it upon the brake *q*, which presses upon the disc *p*, preventing it from turning, and thus the main piston *d* is forced to partially rotate round the twisted bar secured to the disc. But when the main piston makes its forward stroke, and steam or compressed air fills the cylinder *c'*, the motive fluid enters through the small ports *u u*, and presses on the lower end of the piston *l*, thus counterbalancing the constant pressure on the upper end. There being now no pressure on the brake *q*, the disc *p* is free to rotate, and the piston *d* makes its forward stroke without rotating, partially turning the disc as it proceeds by means of the twisted bar.

In all cases a manual feed is to be recommended, as in some rocks the drill will occasionally stick fast. When this happens it takes much longer time to clear the cutting tool if an automatic feed is in use, than in simply giving the handle of a manual feed a turn or two, which is all that is necessary to loosen the drill and permit of the boring being proceeded with. Moreover, the workmen are never so attentive to their work when they have nothing to do but to look on, as they are when they have the machine constantly under hand. Thus, apart from the increased complication and greater wear and tear to which even the best automatic feed motion renders any machine liable, such a feed has always been found objectionable in actual practice.

The feed can be made as long as desirable, but in the large Schram machines it is generally such as to enable holes of 3 ft. in length to be bored without any change of drill points; but the machines are sometimes made with a shorter feed, and consequent reduction of weight and length.

Through the perfectly free action of the main piston, and because the motive fluid is admitted to the whole surface of its upper end, each blow is extremely powerful; moreover this free action, combined with that of the slide piston, allows the machine to be run at a very high speed and enables it to be worked with a very low pressure. Its principal feature, however, is its remarkably small consumption of compressed air, as an air compressor which would only be able to drive one machine constructed on the early systems, will easily drive two of Schram's, the diameter of cylinder being the same in both cases. There being no parts exposed to blows, and the principal parts being directly actuated by the motive fluid, this machine is less liable to wear and tear than those of other systems. It should also be observed that the working parts are all inside the cylinders.

Fig. 1943 is a perspective view of Schram's rock drill mounted on an adjustable tripod.

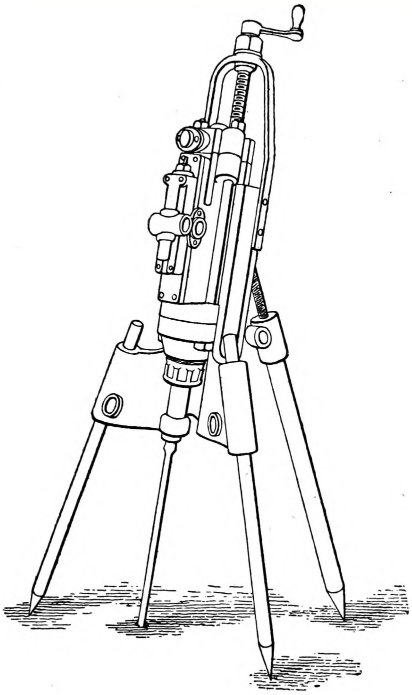
Assuming the necessity for a high degree of strength and rigidity in the support of a rock drill, it should also allow the machine to be readily adjusted to any angle, so that the holes may be bored in the direction and with the inclination required; otherwise the machine is placed, in this respect, at a great disadvantage. If a machine drill is not capable of boring in any position, and in any direction, hand labour will have to be employed in conjunction with it, and such incompleteness in the work of a machine constitutes a serious objection to its adoption.

Besides allowing of the desired adjustment of the machine, the support must be itself adjustable to uneven ground; as the bottom of a shaft which is being sunk, or the sides, roof, and floor of a heading which is being driven, present great irregularities of surface, the support must allow of ready adjustment. Thus the means by which this is effected should be few and simple. A large proportion of the time during which a machine drill is in use is occupied in shifting from one position or one situation to another; and as this time reduces in a proportionate degree the superiority of machine over hand labour, in respect of rapidity of execution, it should be shortened as far as possible.

The drill support must be of small dimensions, and sufficiently light to allow of its being easily portable in the limited space in which rock drills are used. After every blast the dislodged rock has to be removed, and rapidity of execution requires that the operations of removal should be carried on without hindrance. A drill support that occupies a large proportion of the free space in a shaft or heading is thus a cause of inconvenience and a source of serious delay. In underground workings, manual power is generally the only power available, and therefore it is desirable that both the machine and its support should be of such weight that each may be lifted by one man.

In spacious headings, such as are driven in railway tunnel work, supports of a special kind may be used. In these situations, the conditions of work are different from those which exist in mines. The space is less limited, the heading is commenced at surface, and the floor laid with a tramway and sidings. In such a case, the support may consist of a massive structure mounted upon wheels to run upon the rails. This support will carry several machines, and to remove it out of the way when occasion requires, it will be run back on to a siding. But for ordinary mining purposes, it is unsuitable.

1943.



The simplest kind of support is the stretcher bar, Fig. 1944. This consists of a bar so constructed that it may be lengthened or shortened at pleasure by means of a screw. It is fixed in position by screwing the ends into firm contact with the sides, or with the roof and the floor of a heading, or with the side of a shaft. The machine is fixed to this bar by means of a clamp, which, when loosened, slides along the bar and allows the drill to be placed in the required position, and to be directed at the required angle. The stretcher bar, Fig. 1944, is that which is used with the Schram drill; in it rigidity and lightness are combined in the highest possible degree by adopting the hollow section. The mode of setting the stretcher bar in a shaft is indicated in Fig. 1945; in this case two drills are worked upon the same bar. A similar mode of fixing the bar is adopted in a heading; but the usually smaller dimensions of the latter excavations render it inconvenient to work two drills upon one bar.

In headings, a more satisfactory support is afforded by a bar suitably mounted upon a carriage designed to run upon rails. The carriage consists simply of a trolly, to the fore part of which the bar is fixed by some kind of hinge joint. It is obvious that the details of the construction of this support may be varied considerably, and numerous designs have been introduced and adopted.

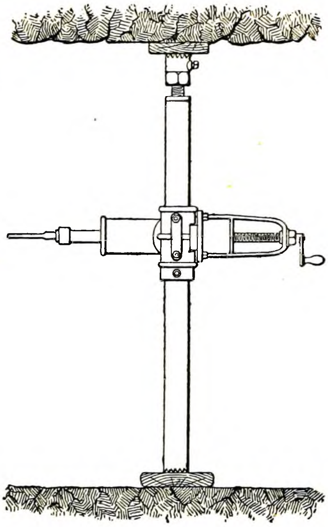
Schram's carriage support, or gadding car, for driving galleries and headings, is shown in Fig. 1946; it consists of two vertical stretchers, on which the rock-boring machines are arranged, and from which they may be directed at any desired angle. Each carriage will accommodate from two to four machines.

When the carriage is at the working face, the stretchers, which during the removal have been lifted by means of nuts, are lowered on to a piece of hard wood; the stretchers are then fastened by upper screws, a piece of wood having first been fixed above their crowns. When the main air-pipe is connected with the carriage, the machine may be levelled to any desired height, and when fixed by the universal joints to which the machines are attached, the boring may at once commence.

When all the holes are bored, and the support must be removed, the stretchers are unfastened by means of the upper screws, and lifted by the lower nuts. Where the heading is not high enough to allow the stretchers to remain upright while the support is removed, it is only necessary to remove the screws by which they are held, and the stretchers can be laid back on the carriage.

It will be seen that this support is easily fixed and removed, and that it allows a free space for the boring machines and the workmen, while the machines may be directed at any desired angle. There is no doubt a great advantage in working with two separate supports, for when the débris from one side has been removed, the boring can be recommenced with one support while the other side is being cleared, and thus a considerable saving of time may be effected.

1944.



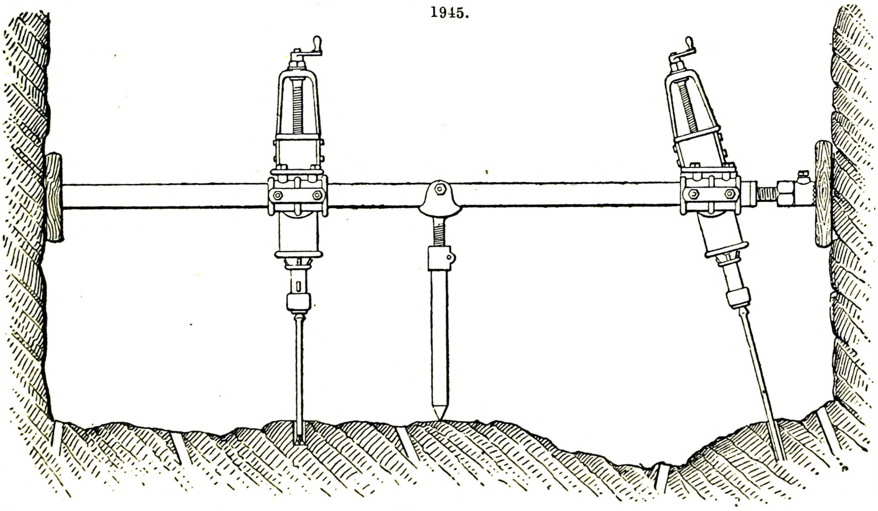
For open work, as in quarrying, where the stretcher bar cannot be used to steady the machine, heavy weights are sometimes hung upon the legs of the tripod, and for the boring of vertical holes, the supports generally employed are tripods. One attached to the machine, Fig. 1943, consists of three legs jointed on to an iron frame. The front portion of this frame is a cylinder on which the rock-boring machine is held by means of a movable universal joint. Each leg can be easily lengthened or shortened by a telescopic arrangement, so as to suit any inequalities of the ground; and so long as the weight of the machine is kept behind the two front legs of the tripod, holes can be drilled vertically or at any slant.

Other machines are fitted with three legs, so that a separate universal joint and tripod are unnecessary. This form is admirably adapted for quarrying and workings where a large number of small holes are required, as one man can comfortably move about and fix the entire apparatus wherever desirable. When it is necessary to bore holes close to a perpendicular wall of rock, the back leg can be removed and the machine allowed to rest against the rock on its two front legs; in this way holes may be drilled at the very foot of the straight wall.

A long, low support for drilling horizontal holes, with a very great resisting power being placed in its rear, can also often be employed to advantage.

In boring holes in a horizontal or downward direction for which water must be used, it is advisable to employ compressed air to inject it. This can easily be done by having a wrought-iron air-tight cistern, either running separately on wheels or attached to the carriage, into which compressed air is admitted by a branch from the main air tubing. From this the water is led to the face by means of flexible tubes, furnished with cocks, allowing a thin stream to be forced into the holes by the air pressure on the surface of the water in the cistern. The attendance of a man or boy to apply this water injector may be dispensed with, by clamping the nozzle or cock-piece to a universal clip working on an irod rod, which, resting against the side or face of the rock, allows the jet of water to be directed into and in a straight line with the hole being bored.

1945.

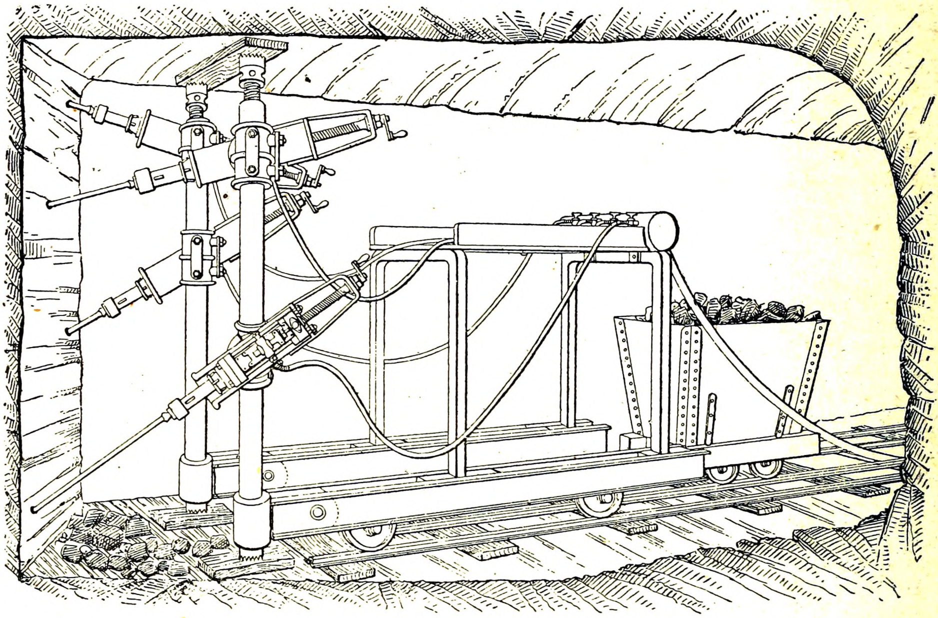


When machines driven by compressed air are worked at any distance from the compressor, it is necessary to have an extra air receiver a short distance from the face, in order to counteract the draw or friction through the tubes, especially if these are of small diameter.

It is sometimes the case that winches and other machinery in different parts or a mine are driven by compressed air, conveyed in branch pipes from the main tubing. In such cases separate air receivers are very necessary, as all fluids have a tendency to rush with the greatest velocity to the largest outlet; and, without receivers to equalize the distribution, machines consuming the least quantity of air would be insufficiently supplied.

Fig. 1947 is an elevation of a complete boring plant, arranged for driving a level and shaft sinking simultaneously. *a* is the boiler; *b*, air compressor worked by steam engine with cranks at right angles; *b'*, connecting pipe between air compressor and air receiver; *c*, air receiver fitted with safety valve and pressure gauge; *d*, air pipe down shaft; *e*, small air receiver, at junction of level with main shaft, to distribute air; *f*, air distributor to distribute air to two or more machines; *g*, flexible indiarubber hose; *h*, rock drills mounted on stretchers *i*; *k*, rock drill for shaft sinking connected with main pipe by flexible hose *j*; *l*, half length of stretcher used for shaft sinking.

1946.



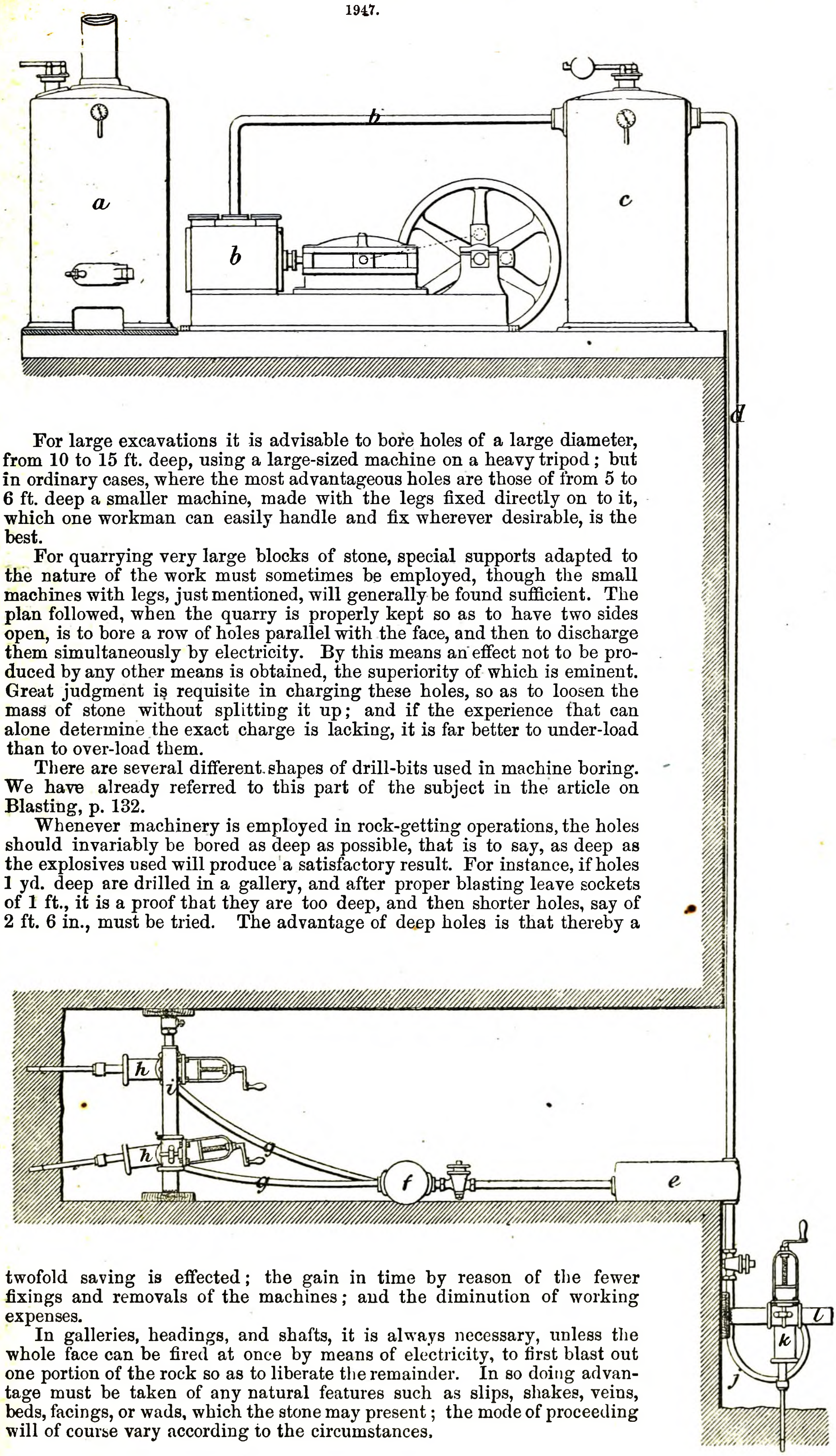
In order to ventilate the face of a heading, it is well to lay a branch length of tubing from the main tubing to the face, with a cock at the junction, so that after blasting, when the air is not for the time required for the boring machines, this cock can be opened and the noxious fumes from the explosives driven out from the face. If this plan is not followed, either the workmen must remain idle for some time, or else the indiarubber hose must be carried up to the face through all the smoke and bad gases, and thus be exposed to considerable damage and knocking about. For the branch tubing, old imperfect pipes may be utilized.

In open blasting above ground, in many places where the quantity of work done is not very great, as in small quarries, and the like, rock-boring machines are often from various causes worked directly by steam. Still, though some rock-boring machines work admirably with steam for the motor, and though by using it instead of compressed air, the saving in fuel is often as much as from 50 to 60 per cent., it is generally advantageous to employ air. When the machines are cold, as is always the case in working with air, they are much easier to fix than when heated with steam; the operator is not inconvenienced by the exhaust steam; the machines require less lubricating; and the hose will last considerably longer. Summing up these advantages, it will be found that the saving in oil, in hose, and in the time occupied in fixing the machines, more than counterbalances the increased consumption of coal, and in a short time defrays the cost of an air compressor. If there be available water power to drive the compressor, of course the advantage is all on the side of air. Moreover, if steam be carried a long way, large tubes must be used, and the pressure is also materially reduced; and every rock-boring machine works better at a low pressure when driven by compressed air than it does when steam is used.

It is almost invariably found that whenever hand borers first commence to use machines, they endeavour to follow their old custom of putting in holes here and there indiscriminately; this must at once be stopped, and regular systematic working insisted upon. For instance, in open blasting they must proceed in steps, or tiers, and bore the holes in rows. By so doing the total result of the blasting is infinitely greater, because the holes have a better general effect; and a good place for fixing the machines being always procured, there is a great saving in time.

The rows of holes should, in most cases, be discharged by electricity, so that through their simultaneous explosion the greatest possible effect be obtained. Isolated holes not connected with the system may be fired one after another by safety fuse.

1947.



For large excavations it is advisable to bore holes of a large diameter, from 10 to 15 ft. deep, using a large-sized machine on a heavy tripod; but in ordinary cases, where the most advantageous holes are those of from 5 to 6 ft. deep a smaller machine, made with the legs fixed directly on to it, which one workman can easily handle and fix wherever desirable, is the best.

For quarrying very large blocks of stone, special supports adapted to the nature of the work must sometimes be employed, though the small machines with legs, just mentioned, will generally be found sufficient. The plan followed, when the quarry is properly kept so as to have two sides open, is to bore a row of holes parallel with the face, and then to discharge them simultaneously by electricity. By this means an effect not to be produced by any other means is obtained, the superiority of which is eminent. Great judgment is requisite in charging these holes, so as to loosen the mass of stone without splitting it up; and if the experience that can alone determine the exact charge is lacking, it is far better to under-load than to over-load them.

There are several different shapes of drill-bits used in machine boring. We have already referred to this part of the subject in the article on Blasting, p. 132.

Whenever machinery is employed in rock-getting operations, the holes should invariably be bored as deep as possible, that is to say, as deep as the explosives used will produce a satisfactory result. For instance, if holes 1 yd. deep are drilled in a gallery, and after proper blasting leave sockets of 1 ft., it is a proof that they are too deep, and then shorter holes, say of 2 ft. 6 in., must be tried. The advantage of deep holes is that thereby a twofold saving is effected; the gain in time by reason of the fewer fixings and removals of the machines; and the diminution of working expenses.

In galleries, headings, and shafts, it is always necessary, unless the whole face can be fired at once by means of electricity, to first blast out one portion of the rock so as to liberate the remainder. In so doing advantage must be taken of any natural features such as slips, shakes, veins, beds, facings, or wads, which the stone may present; the mode of proceeding will of course vary according to the circumstances.

When the rock is solid it will generally be found most advantageous to bore rows of holes directed towards the centre, to be fired before the side holes, which they are intended to liberate. These liberating holes for the most part require charging a little heavier than the side holes.

The rate of progress which is possible by using rock drills instead of hand labour is exceedingly difficult to estimate, inasmuch as it depends to so large an extent upon the local peculiarity of a rock, which is an ever-varying quantity. No calculation can be based upon the statement that a given rock drill will bore a certain number of holes the given depth in granite in a minute, since there are no two granites alike, either in composition or mechanical structure, whilst it is a well-known fact that granite is by no means the hardest or most difficult rock with which an engineer has to deal. As an approximate guide, however, the following data obtained from practice with one good rock drill of modern construction, having a cylinder of $2\frac{7}{8}$ in. diameter, and working in a level of 7′ by 7′, is of interest; the time occupied in each case was four weeks, the explosive dynamite.

PROGRESS MADE WITH ONE ROCK DRILL.

Strata.	Pressure of Air.	Distance.
	lb.	yds.
In sandstone conglomerate	40	30
,, mountain limestone	34	28
,, Cornish capel	50	18
,, green stone	50	16
,, granite	45	20

ROLLING STOCK.

The improvements which have been effected in the construction of passenger rolling stock since the introduction of railways are very considerable, but nowhere is this more noticeable than in the case of third-class carriages. At first the third-class carriages employed for short distances were simply open trucks, without any seating accommodation; for longer journeys seats were provided, but no kind of protection from the weather, or from the dust, or sparks from the engine. Now we find the third-class carriages on many lines rivalling in comfort and convenience the accommodation provided for first and second-class passengers.

In the present article we have endeavoured to present as large a number as possible of the different types of British, Continental, and American passenger carriages and goods waggons, so as to show the present most approved and generally practised methods of construction, rather than an elaborate treatise on the scientific principles of construction.

For passenger traffic, long carriages will be found to run very much easier and steadier than short ones; while in cases of collision they are considerably safer, being not nearly so likely to mount on each other as the shorter and consequently lighter carriages. This fact is very generally recognized at the present day; for whereas formerly all passenger carriages were carried on four-wheeled underframes, the first-class carriages consisting of three compartments, and the second and third usually of four compartments each, we now find the carriages constructed with five, six, or more compartments each, carried on underframes supported by six wheels, or by two four-wheeled bogie trucks placed near the ends of the underframe; and besides this increase in the number of compartments, the several compartments are now much longer than they were formerly made, which still further increases the length of the carriage.

As regards the seating of passengers, the safest way, though not perhaps the most sociable, is that adopted in omnibuses or tram-cars, namely, longitudinally, shoulder to shoulder, instead of face or back to the engine; the risk of serious injury from any violent concussion being much less with the former method of seating than with the latter.

The underframe is the foundation of the vehicle; it should be simple, durable, and strong, easily repaired, easily maintained, and should carry its load and resist concussions without injury or alteration of form. The alterations of form to which underframes are most liable are, hogging, or drooping at the ends, rising at the middle like the back of a hog; and going out of square horizontally, so that the frame ceases to be rectangular. Both of these affections are injurious, the first chiefly because it strains the body, or upper works, loosening the joints, splitting the panels, and jamming the doors; the second because it also strains the body, and besides deranges the wheels and axles, causing irregular movements on the rails. One great and principal cause of hogging arises from the frame being unequally supported by the springs; as, for example, when the centres of the axles are too near, leaving the ends insufficiently supported. Hogging may be partially checked by placing the heart side of the sole uppermost, and by placing the wheel centres sufficiently far apart, at a little over half the total length of the underframe; or it may be entirely prevented by stiffening the frame with iron plates, or by trussing. The conditions necessary to be fulfilled in order to obtain a strong, simple, and durable underframe are, that it shall be simple in its arrangements, few in its parts, direct in its connections, and completely defended by springs.

Wheels and Axles.—The body of the wheel should be independent of the tire for its form and strength, so as to remain unalterable whatever may be the condition of the tire. For this reason, the spokes of the wheel should be sufficiently numerous to maintain the rim inflexible; a 3-ft. wheel having a minimum of eight spokes, which would give, at the rim of the wheel, intervals of 12 in. between the spokes. Disc wheels are, however, much to be preferred to spoke wheels, as they may be more simply made, and afford a continuous bearing to the tire.

The tire, or wearing part, should be quite distinct from the body of the wheel, so as to be readily renewable, and should consist of a rigid ring, capable of preserving its form even after it is well worn. The most usually employed material, both for tires and axles, at the present time, is Bessemer steel.

The body of the wheel should possess some amount of elasticity, so as to cushion the blows radially, and to resist those from lateral concussions; a condition which is admirably fulfilled by Mansell's wooden disc wheels.

The necessary variations in the diameter of the axle should be made gradually by a series of undulations or curves; not suddenly, by steps: so that the elasticity of the axle may be uniform, and the pulsations by concussion uninterrupted. The fulfilment of this condition greatly promotes the durability of the axle, a square neck or shoulder being an incipient fracture, which sooner or later is sure to produce failure in the axle.

Axle Boxes.—Axle boxes are in good working order when the lubrication is free and constant; when there is no heating, no waste of grease; when the external dust and grit are excluded; when there is no lurching fore and aft, and no injurious end play. In order to fulfil these conditions, the bush should fit easily upon the journal, and should be tight nowhere; the grease chamber should be capacious and kept full of grease; the grease holes should be wide, and should be occasionally probed to clear the passages; the axle box should be entirely closed upon the journal; and there should be provision for readily compensating the end wear.

Axle boxes should be of toughened cast iron, and they may be in one main casting, in two castings, or in three. The fewer the pieces, the less is the probability of loose working or noisiness; but the less is the convenience also, for by casting the cover and the bottom separately from the body of the box, they may be removed at any time, and the interior freely inspected and cleaned out; while by properly fitting and fixing the castings together, the cover being held down simply by the spring, and the bottom fixed up by two bolts and cotters, with a thin packing of leather or hemp to take off the concussions, a practically tight and solid box is obtained.

The guiding grooves on the outside of the axle box should be of the full depth of the box, to ensure steadiness, particularly if the spring be not bolted to the box; they should be only just slack, longitudinally, between the horns of the guard, so as to keep the axles square; and for high speeds they should be only $\frac{1}{8}$ in. wider than the thickness of the guard, laterally; but for low speeds, of under 20 miles an hour, they may be $\frac{1}{4}$ in. wider, as the lateral freedom steadies the motion, and reduces the tractive power required.

Bearing Springs.—The bearing springs are formed of steel plates, of a general width of 3 in., by $\frac{5}{16}$ in. thick; the top and bottom being $\frac{3}{8}$ in. thick, and the number of plates nine or ten. The springs have usually, in addition, a tension plate of wrought iron, $\frac{1}{2}$ in. thick, placed upon the top plate; eyes are worked in the ends of this tension plate to receive the suspending links, which are pinned to them and to the scroll irons, these latter being simply plain wrought-iron brackets, which are bolted to the underframe. The ordinary length of the springs, when weighted, is about 5 ft. 3 in., the tension plates 5 ft. 6 in. to the centres of the eyes, and the scroll irons 6 ft. apart between the centres.

The spring should not be bolted rigidly to the axle box, but should be simply placed upon it, to promote free action, and sufficiently checked to prevent lateral displacement.

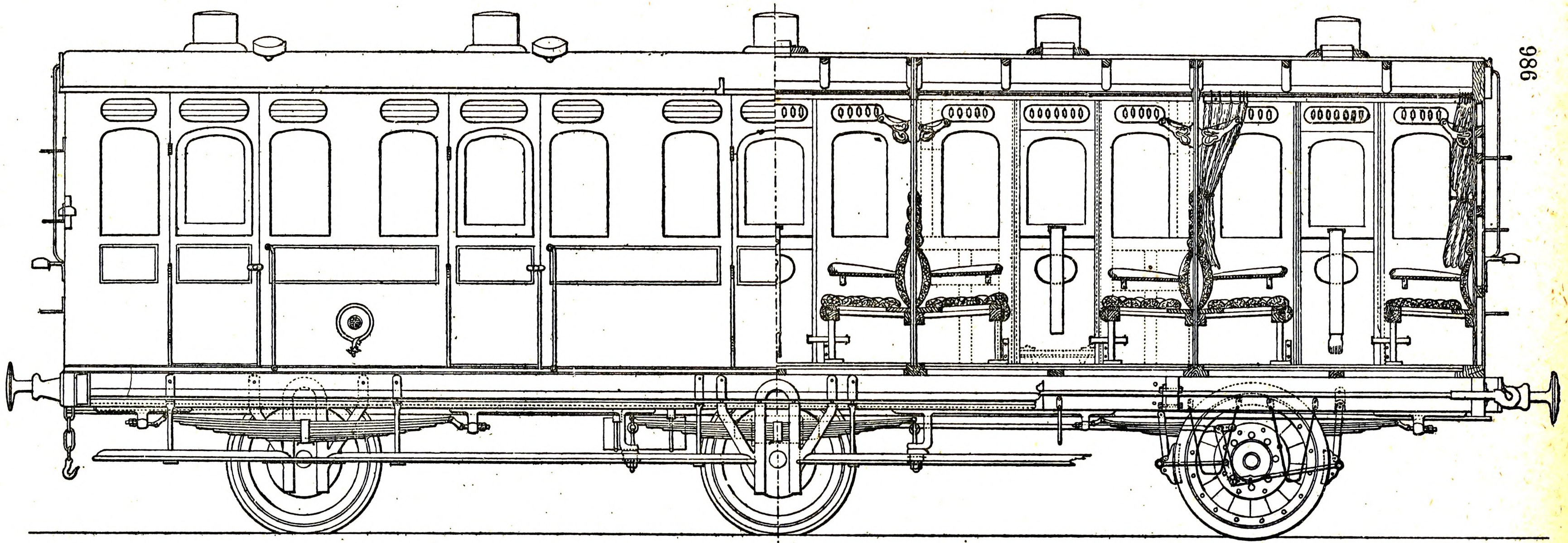
Axle Guards.—Axle guards, or horn plates, are formed of wrought-iron plate, $\frac{5}{8}$ in. to $\frac{3}{4}$ in. thick, and are bolted to the inside of the side soles, and they are generally made of the form known as the W. In these the guards are usually of bar iron 3 in. wide, doubled up at the forge to form the guides or horns, and with wings of bar iron $2\frac{1}{2}$ in. to 3 in. broad, welded to the guides near their lower ends, and carried up with a spread to join the side soles; the guards being $\frac{3}{4}$ in. thick, and secured to the side soles by $\frac{3}{4}$-in. bolts and nuts, three in the bend and two in each wing, making seven in all. The extreme bolts in each guard may be as much as 3 ft. apart; for the farther apart the more command they have over the wheels and axles. Laterally, their stiffness depends on the depth of their hold upon the side soles, and they should therefore be applied for its whole depth, or as much of it as may be convenient. Besides the spread, the solidity of the bolt fastenings is to be regarded. If the bolt heads be received, on the outside, merely on washers, they are likely to work loose in the timber, which is wanting in firmness to resist the tendency of the bolt holes to wear ovally. The bolt heads should be received upon large washer plates, $\frac{1}{4}$ in. thick, counterparts, in fact, of the bearing surface of the guards inside; these washer plates, embracing a large surface of timber, bear solidly and firmly, and keep the bolts tight. A still better plan, both for simplicity and firmness, is to cover the whole area of the side sole at each guard with sheet iron to the depth of the sole; or where the side soles are plated over their whole length and depth, for the general purpose of strength and simplicity, no washer plates are required at all, and at the same time the best possible surface is afforded for bolt hold.

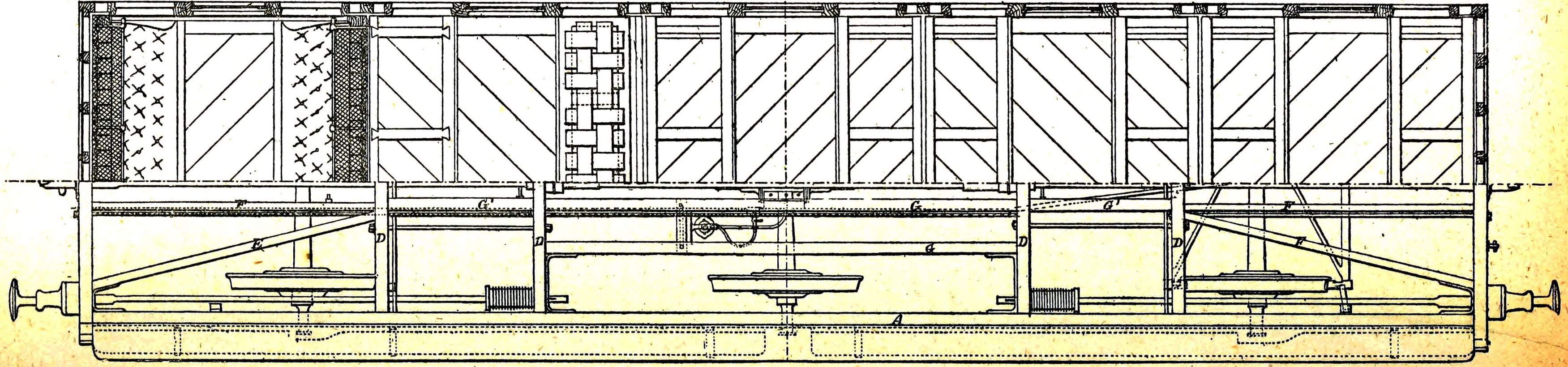
The ends of each bar are tied together by a strap bolted to them, and it is common also to connect the guards, on each side of the vehicle, with a $1\frac{1}{4}$-in. round tie-rod, in order to stiffen the guards and to assist the frame; this tie-rod being formed either in one forging with the straps, or separately bolted. The separate attachment is better then the continuous forging, as the straps may in the former case be more conveniently removed when the wheels and axles have to be taken out; besides which, when the continuous forging is removed, the underframe obeys its natural tendency to collapse, or hog, and consequently it is troublesome to replace the tie.

Buffing and Draw Springs.—These springs vary considerably, both in their form and material. Sometimes laminated steel springs, similar to the bearing springs, are employed; in other cases, they are formed of circular discs of indiarubber, these discs being strung upon the buffing or draw rods, and the separate discs being kept from contact by means of thin plates of metal placed between them. A third form of spring employed is the helical or spiral spring, which is formed of a rod of steel twisted into a coil or volute, the section of the steel rod being usually circular, but sometimes oval; the volute proper is made of a plate of steel twisted into a coil. In some cases one set of springs are made to do duty both as drawing and buffing springs.

Further particulars concerning, and remarks upon the construction of, wheels and axles, and

1948.

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1951.

springs, will be found under the head of Goods Waggons, and in the article **Axles** and **Axle Boxes** in this Dictionary.

Figs. 1948 to 1951 relate to a second-class carriage of the Great Eastern Railway, fitted with the Westinghouse automatic brake. This carriage is divided into five compartments, and is carried on six wheels, the end pairs and those in the centre being somewhat differently mounted. The materials employed in the construction of the carriages of which this is a type are throughout of the very best quality, and the workmanship and style of finish are altogether of a very superior description, so that the carriages are excellent specimens of the present style of passenger rolling stock construction. Fig. 1948 is a half side elevation and half longitudinal section; Fig. 1949 a half end elevation and half cross section; Fig. 1950 a cross section showing attachment of brake blocks, and Fig. 1951 a half plan of bottom framing and half plan of interior of carriage.

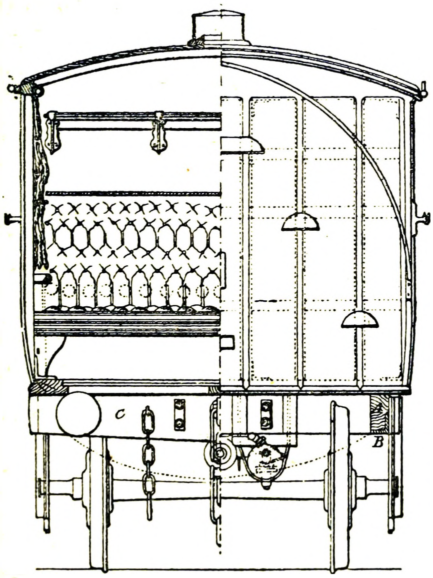
The principal dimensions of this carriage are as follows;—

	ft.	in.
Length of bottom frame over headstocks	31	5
Width ,, ,, ..	7	10
Length over all	34	11
Width over sole bars	7	0½
,, ,, bottom stepboard	8	4
,, ,, top ,, ...	8	8
Distance between centres of buffers ..	5	8
Height of centres of buffers above level of rails	3	5
,, bottom stepboard above level of rails	1	9½
,, top stepboard above level of rails	3	2½
Length of body	31	6
Width ,, ...	7	6
Height ,, outside, at sides ..	6	4

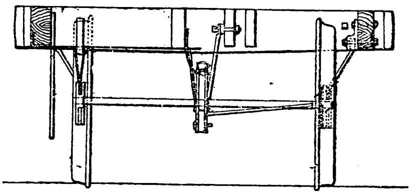
	ft.	in.
Height of body outside, at centre ..	7	0
,, ,, inside, at sides	6	1
,, ,, ,, at centre ..	6	8¾
Width of each compartment	6	1½
Total height above level of rails ..	11	7
Diameter of wheels	3	6½
Distance between wheel centres ..	10	0
Total wheel base	20	0
Width of tires	0	5
Distance between centres of journals	6	7½
Diameter of journals	0	3¾
Length ,, ...	0	8
Diameter of axle at centre	0	4⅛
,, ,, wheel seat	0	5
,, ,, back of wheel seat	0	5⅛
Distance between guards, centre wheels	7	0½
,, ,, ,, end ,,	6	1½

The underframing is constructed of well-seasoned North American white oak, and consists of sole-bars A, 9½ in. deep by 4½ in. wide, placed 6 ft. 3½ in. apart, an angle iron B, of BB Staffordshire iron, 4½ in. by 3½ in. by ½ in., being recessed into each of them at the outer bottom angle.

1949.



1950.



The headstocks C are 4 in. wide by 11 in. deep at the centre and 10 in. at the ends. Four cross bearers D, 10 in. by 4 in.; four diagonals E, 10 in. by 2½ in.; four end longitudinals F, 10 in. by 2½ in. by 7 ft. 1½ in.; and six intermediate timbers G, 10 in. by 3½ in. by 8 ft. 2 in., and four G′, 10 in. by 3½ in. by 3 ft. All of these timbers are framed together with mortises, tenons, joints, and ironwork, the whole well fitted, and bedded in white-lead, and bound together with wrought-iron corner knees, and straps, fixed with ¾-in. bolts, and ⅞-in. tie-rods, secured with nuts bearing on washer plates. Each piece is marked from a template, so as to be interchangeable with any similar piece from another frame.

The tires and axles are of best Bessemer steel; the body of the wheel being of dry, well-seasoned Moulmein teak. The boss and washers are of cold-blast iron; and the sustaining rings of best Lowmoor iron, interchangeable, drilled, and turned to gauge and template. The tires are 2¼ in. thick and 3 ft. 6½ in. diameter on the tread; and they are forced cold upon the wheels with a pressure of 200 tons, the wheels being forced on the axles with a pressure of 40 tons and keyed.

The tires are tested by taking one out of every fifty, and pressing it, when cold, into an oval form, by hydraulic power, when it must be capable of bearing, without fracture, a compression of 2 in. for each foot of external diameter. The axles are capable of standing, without fracture, five blows from a 2000-lb. weight, falling from a height of 20 ft., the axle being placed on bearings 3 ft. 6 in. apart, and turned after each blow.

The axle boxes are of cast iron, in two parts, and are secured by ¾-in. bolts, the brasses being ⅞ in. thick. These boxes are intended for lubricating with oil.

The axle guards are of BB Staffordshire iron, $\frac{3}{4}$ in. thick; the end guards being secured inside the soles at 20 ft. centres, and the centre guards stiffened by angle iron 3 in. by 2 in. by $\frac{3}{8}$ in., fixed outside by $\frac{3}{4}$-in. bolts.

The bearing springs at each end consist each of ten plates $\frac{1}{2}$ in. thick and $3\frac{1}{2}$ in. wide; the springs to the centre wheels consisting of nine $\frac{1}{2}$-in. plates and $\frac{1}{2}$-in. iron packing piece; the eyes being forged solid on the top plate. The top plate of each spring, when straight, measures 7 ft. from centre to centre of eyes. The spring buckles are made of best Yorkshire iron, and are $3\frac{1}{4}$ in. wide by $\frac{1}{2}$ in. thick, the bottom being $\frac{5}{8}$ in. thick to clip the axle box. The centre spring buckle has a spherical bearing at bottom working in a recess on top of axle box; a $\frac{3}{8}$-in. rivet of the best cast spring steel, made from Swedish iron, passing through the centre. Each spring is tested with steam and a dead weight, until all the camber is taken out, after which it must, upon being released, resume its original form.

The draw gear is made of Yorkshire best iron; the draw bar being $1\frac{3}{4}$ in. in diameter at centre; the side chains $\frac{7}{8}$ in. in diameter; the screw coupling links 1 in. in diameter, with screw $1\frac{3}{8}$ in. in diameter, and five threads to the inch.

The buffer springs are of indiarubber; there being, in each spring, ten rubbers $4\frac{1}{2}$ in. by $2\frac{1}{2}$ in., and the discs separated by washers $\frac{3}{16}$ in. thick. The buffer heads are of wrought iron, 12 in. in diameter and $\frac{5}{8}$ in. thick at the edge. The buffer rods are turned $2\frac{1}{2}$ in. in diameter for a length of 2 ft. 6 in. from the back of buffer head, the middle part $1\frac{3}{4}$ in. square, and the ends turned to a diameter of $1\frac{1}{2}$ in. to receive the buffer springs.

The body framing is of pitch pine; with the exception of the corner and standing pillars, upright battens of end framing, and elbow rails, which are of best Dantzic oak; and the top light rails, which are of Moulmein teak. The outside panels and mouldings are of best teak, the former being full $\frac{3}{8}$ in. thick; these panels and mouldings being fixed with copper carriage pins. The inside casing is of $\frac{1}{2}$-in. pine boards, and the partitions of best Petersburg deals. The floorboards are of best Petersburg deals, in two layers, $1\frac{1}{8}$ in. thick when finished; the boards being laid diagonally, and put together with 3-in. screws, No. 16. All joints have a coat of white-lead before being put together; and the bottom, sides, and pillars are bound together with wrought-iron knees. The body is cushioned with Spencer's indiarubber springs. The windows and side lights are fitted with best polished plate glass $\frac{3}{16}$ in. thick; the side lights having indiarubber strips on both sides of the glass in lieu of putty.

Two continuous footsteps of pitch pine, $1\frac{1}{2}$ in. thick, are provided on each side of the carriage.

The hoop-sticks of the roof are of best ash, cut to the camber of the roof; the arch rails pitch pine; roof boards of best Petersburg deals, $\frac{3}{4}$ in. thick, tongued and grooved, and secured to hoop-sticks with $1\frac{3}{4}$-in. screws, No. 16. The roof receives five coats of stout lead paint before being covered with roofing canvas, and then five coats of white-lead paint on the canvas; the latter being carefully brought over the edge of the roof and secured under the gutter.

The internal fittings comprise curtains, hat cords, parcel netting, rails, and bracket, and carpets. The backs and cushions of seats are stuffed with horsehair; and padded arm rests are provided at each end under the windows. Two compartments, reserved for smokers, are covered with black horsehair cloth, and the remaining three with green Utrecht velvet. Ventilators are placed over each door and each side light; these ventilators being covered outside with a metal hood open at the bottom; the inside consisting of two perforated panels, one fixed, the other sliding, so as to be closed or opened at pleasure. The smoking compartments have smoking tablets fixed on the outside of the quarter lights. Each compartment is fitted with an 8-in. roof lamp.

The carriage is fitted with the Westinghouse automatic brake. All holes in the brakework and blocks are drilled, pins turned, and wearing parts case-hardened; the main pipes are of iron, best steam pipe quality, and the smaller pipes of best soft copper solid drawn, $\frac{1}{2}$ in. outside diameter, No. 11 B.W.G. thick. The brake is tested, when completed, with an air pressure of 100 lb. to the square inch; under which pressure it must show no leakage, and must come on, or off, promptly.

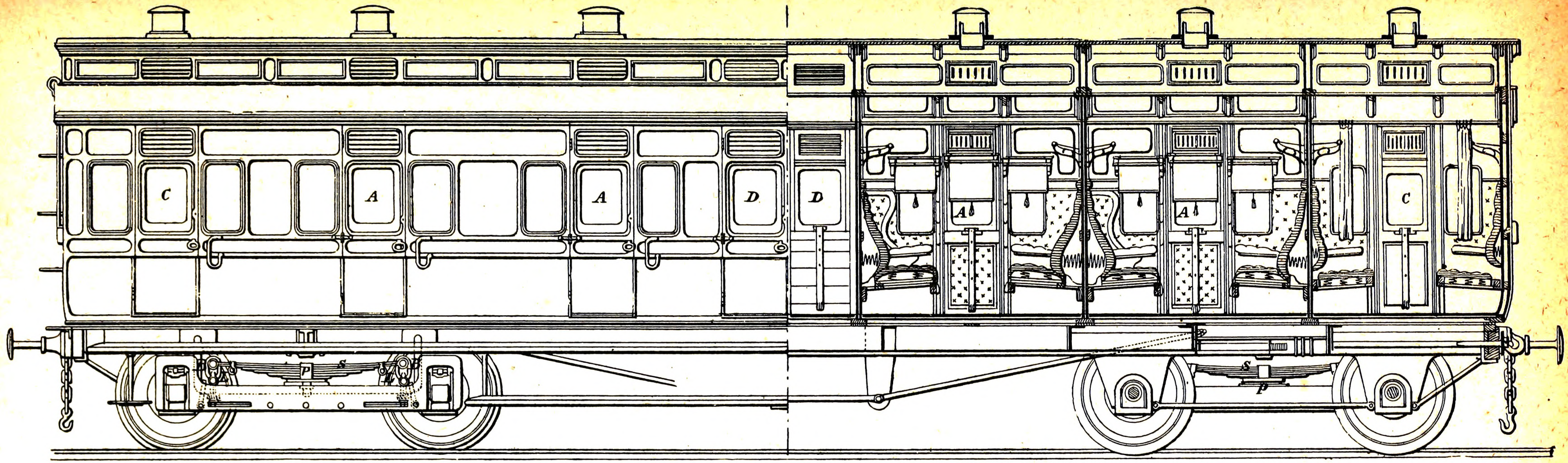
All ironwork is of best hammered scrap iron; and all bolts and nuts are of Whitworth's standard thread; unless otherwise specified.

The woodwork of the wheels has four coats of varnish; the boss and rings are painted black, and varnished; and the axles and outer edges of the tires are painted white. The springs, stepboards, and axle boxes have two coats of lead colour, and one coat of oil black; the ironwork on underframe receives two coats of lead colour, two coats of bronze green, and lastly two coats of varnish. Care is taken that all dirt, rust, and scale is removed from the ironwork before painting.

The interior is painted as follows;—The knots in deal are first knotted, then one coat of flesh colour all over, then well sand-papered and puttied, and afterwards two coats of ground colour; the partitions and ends being cream colour, and the other portions grained teak; the whole lastly receiving two coats of good first coating body varnish. The interior of the roof has two coats of oil white, and one coat of flat white. The floor is lead colour. The lap plates, corner plates, doorway plates, &c., are painted and grained teak. The inside of doors, and round the side lights are well French polished; and the woodwork underneath the seats is painted lead colour.

A composite carriage of the Great Western Railway, built at the company's works at Swindon, from the designs of Joseph Armstrong, is shown in Figs. 1952 to 1954. Fig. 1952 is a half side elevation and half longitudinal section, Fig. 1954 is a half end elevation and half cross section, and Fig. 1953 is a half plan of framing and a half sectional plan of interior. This carriage is carried on two four-wheeled bogies, arranged with side pivots, that is, a pivot P at the centre of each side frame of the bogie, this arrangement being adopted in order to check the tendency to oscillation which is often found to exist in bogies with a single centre pin. Two pairs of springs S are carried on each bogie, one pair on each side frame being fastened to the same pivot. Each pair of these springs are connected at their ends by one pin passing through the two opposite eyes, these pins carrying the suspended links L by which the carriage is supported, the weight being taken from the suspending links by the heavy wrought-iron hanger bars B, which pass down between the two

1952.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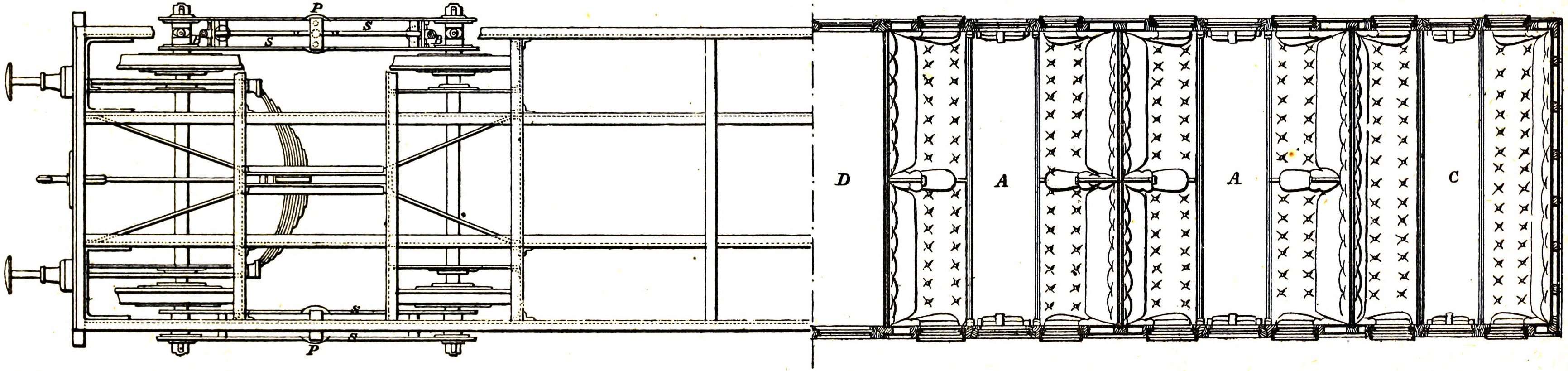
P
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1954.

side plates of the bogie framing, and there receive the ends of the eye-bolts carrying the suspending links; these hanger bars are shown in the side elevation Fig. 1592, and in section in Fig. 1593. It will thus be seen, that the extent to which each bogie can rotate to accommodate the wheels on a curve, is dependent upon, and limited by, the range of oscillation admitted by the suspending links; but this, although not great, is sufficient to allow of the necessary motion of the bogie, while the carriage travels exceedingly steady, and with very little oscillation in any way. These carriages are supported on their bogies so near the ends of their frames that there is practically no overhang; the only tendency to sagging being that most easily prevented, namely, between the supports. The horn stay, seen underneath the carriage frame inside the wheels, is intended to act as a safety-guard in case of breakage of the journal, or any part of the outside bogie frame. Sufficient play is allowed to the axles to permit of free play in all directions.

The principal dimensions are;—

	ft.	in.
Length over buffers	49	0
,, of body	45	6
Width of body	10	1
,, inside.	9	6
Length of first-class compartments	7	0
,, second-class ,,	6	0
Height above floor to underside of roof at sides	7	1
,, ,, ,, raised central part of roof	8	6

Framing:—Sole bars, wrought-iron angle plates, 9 in. by 3½ in. by ½ in.; headstock, oak, 12 in. by 4½ in.; angle iron at back of headstock, 9 in. by 3½ in. by ½ in.; angle iron stiffeners, 8 in. by 3½ in. by ½ in.

Bogie:—Wrought-iron plates, 8 in. by ½ in.; angle irons, 2½ in. by 2½ in.; distance between centres of bogie frames, 30 ft.; distance between centres of wheels of each bogie, 8 ft. 3 in.; total wheel base, 38 ft. 3 in.

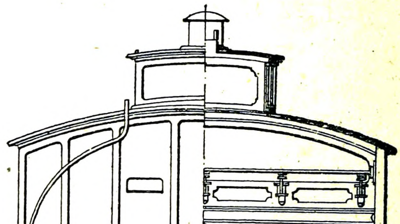
Wheels:—Diameter, 3 ft. 6 in., wood centres, Mansell's tire-fastenings; tires, 5 in wide; axles wrought iron, with case-hardened journals; centres of journals, 8 ft. 10 in.; journals, 4 in. diameter, 10 in. long.

Springs:—Eight laminated bearing springs, 6 ft. centres, each spring composed of ten plates 4 in. wide, namely, nine plates ½ in. thick, and one plate ⅝ in. thick; two laminated steel buffing and drawing springs 6 ft. long, each spring composed of nineteen plates 3 in. wide, namely, eighteen plates ⅜ in. thick, and one plate ½ in. thick.

Total weight, 18 tons 10 cwt. empty; or a dead weight of 7·1 cwt. a passenger.

The carriage is divided into four first-class compartments A, seating eight passengers each, two second-class compartments C, one at each end, seating ten passengers each; and a central luggage compartment D; each passenger compartment being lighted by two lamps of an improved pattern. Accommodation is thus provided for fifty-two passengers; but for short journeys four more second-class passengers may be carried, making a total of fifty-six. The first-class compartments have walnut panelling with gilt mouldings, and are trimmed with blue cloth; they have also spring blinds of a new construction, which are considered less likely to get out of order than the description formerly in use. The second-class compartments have mahogany fittings, and are trimmed in blue rep. In addition to the usual ventilators in the doors, louvre ventilators of a special form are placed in the raised portion of the roof, thus keeping the carriages thoroughly well ventilated without draughts.

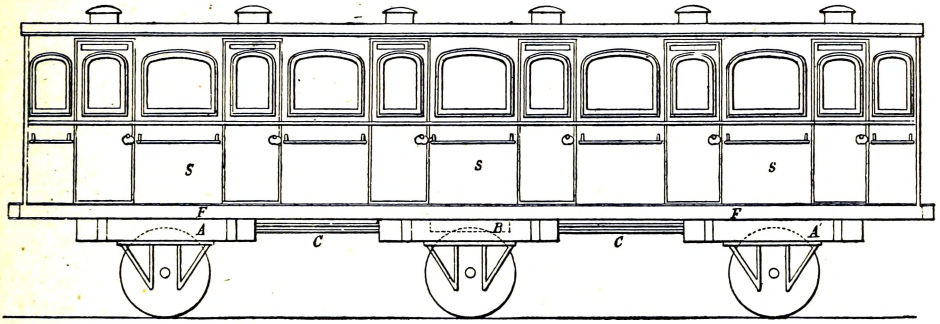
1954.



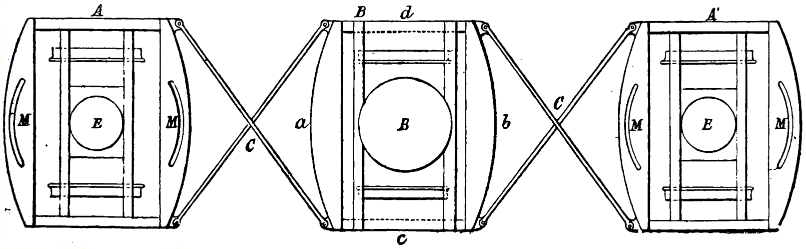
These carriages were specially designed for the broad-gauge express trains from Paddington to the West of England, and are constructed so as to be easily converted to the narrow gauge if this should be required. They have given every satisfaction for comfort, stability, and steadiness in travelling.

Fairlie's improvements in the construction of six-wheeled bogie carriages are indicated in Figs. 1955 and 1956; Fig. 1955 is a side elevation of a carriage built on this principle, and Fig. 1956 a plan of the three bogie trucks. The object of this arrangement is to enable the wheels, and the bogie frames or trucks which carry them, to adapt themselves in a better manner to curves of the line, without imparting their swivelling movement to the body of the carriage. For this purpose three bogie or swivelling trucks A A′ B are employed to each carriage, each truck being provided with a single pair of wheels; and these trucks are connected together by suitable diagonal couplings or braces C, and support a rigid frame or carrier F, upon which the body S of the carriage is mounted. Each of these trucks has a bogie centre E to receive a pin P on the rigid frame, the pins being preferably of large diameter; but the middle truck B, instead of having a simple centre to turn or swivel on the pin, is formed with a transverse slide or groove K, Fig. 1957, which is free to travel along the pin, in accordance with any sidelong movement imparted to the truck by the construction of the line, the truck being also free to turn on the same pin. The pin P, Fig. 1958, is rounded as shown to allow either of the wheels of the middle truck to rise or fall on going round sharp curves; and as the part L of the frame F does not quite touch the bogie truck, a little freedom is allowed for this rise or fall; indiarubber pads or cushions faced with metal being placed between the frame F and the side frame of the bogie truck at N. Each of the outside trucks A A′ is formed at each end with a curved slot M, struck from the bogie centre, and the rigid frame F is provided with pins to take into these curved slots, so that while each of the trucks is free to swivel independently without affecting the movement of the rigid frame, the swivelling movement is properly controlled.

1955.

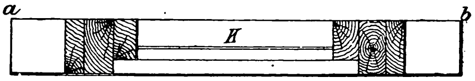


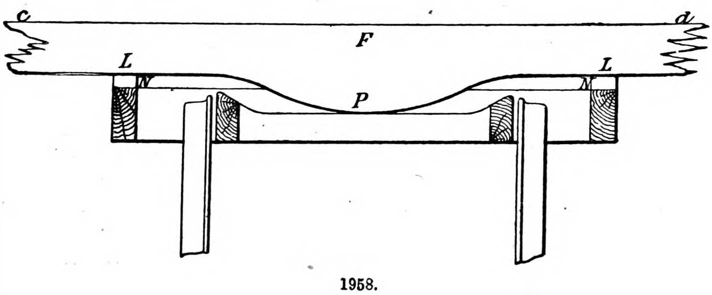
1956.



A third-class carriage of the Southern Railway of France, constructed at the Company's works at La Villette, from the designs of Regray, is shown in Figs. 1959 to 1961; Fig. 1959 is a half longitudinal section and half side elevation; Fig. 1960 a cross section, and Fig. 1961 a plan of interior of carriage. The frame of this carriage is wholly of iron; the soles are of I section, 8·66 in. by 3·93 in. by 0·39 in.; headstocks of channel section, 8·66 in. by 2·75 in. by 0·39 in.; three intermediate transverse bearers, also of channel section, 4·5 in. by 1·96 in. by 0·47 in.; and four diagonals of 3·14 in. by 1·96 in. by 0·31 in. angle iron, these latter passing over the tops of the transverse bearers, the whole framing being well connected by corner brackets and gusset plates. The axle guards are 1 in. thick, and are bolted to the frames. The bottom, sides, end, and intermediate bars, and cant-rails are of oak, the door and corner pillars and rails are of ash, and

1957.

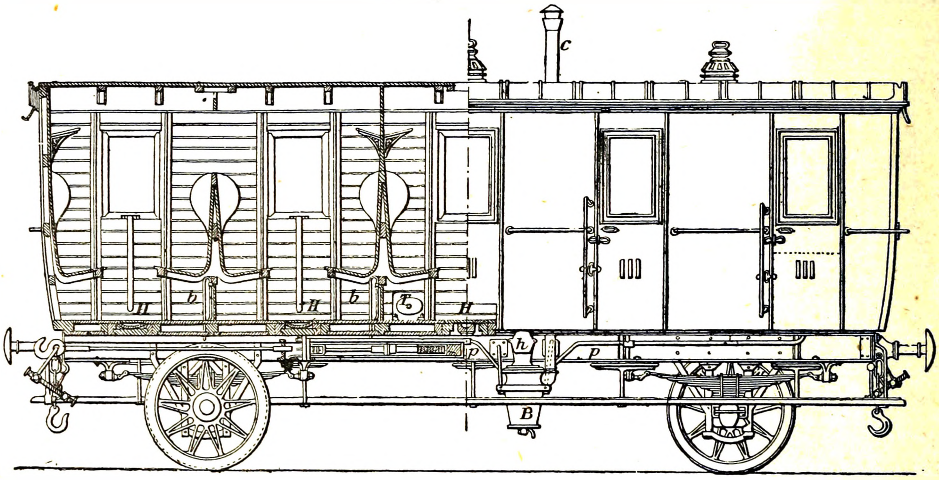




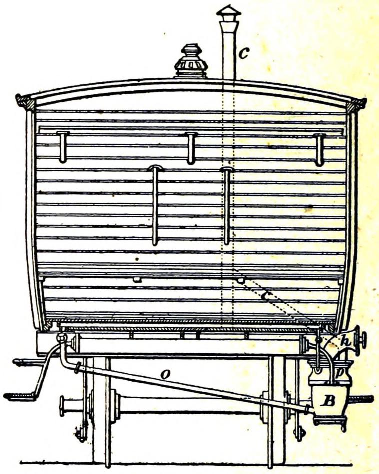
1958.

the lining of pine. The panels are of sheet iron, ·06 in. thick, and extend the whole height of the body, the joint covers being also of iron. The roof is covered with sheet zinc, laid with folded joints, and secured by iron cover strips, which are screwed to the roof-sticks. The floor of the body is double, as shown in the sections. The axle boxes are made for oil lubrication, a pad contained in the lower part of each box being pressed up against the axle by a spring, and the back of the box being closed by a collar of leather or felt, made in two parts with crossed joints; the box is made in two parts, which are held together by a couple of bolts, the joint being made by the interposition of a leather ring. The guides are on the upper part only, and they are made so as to give each axle box a play in the horn plates of ·12 in. in each direction transversely, and ·16 in. in a direction perpendicular to the axle. The draw-bar is continuous, the centre portion of its length being made up of a couple of links, one of which passes over and the other under the draw and buffer springs. The buffer springs are independent of the draw-springs, but when in place they are connected so as to have a compression corresponding to a load of 1·6 tons, while the screw coupling is proportioned, so that when the carriages are coupled up in a train there may be a normal strain on these springs of about 2·2 tons, this sufficing to ensure steadiness. The buffer springs are fixed at the centre of the carriage, so that they may abut directly on each other without putting a strain on the framing. The buffer rods are guided at their outer ends, and are connected to the top plates of the buffer springs by links. The principal dimensions of this carriage are;—

1959.



1960.



	ft.	in.
Frame;—		
Total length over buffers	23	3
„ width over footsteps	10	2
Length over headstocks	22	11·6
„ of headstocks	8	8·3
Height of top of soles above rails	3	9·7
Height of centres of buffers above rails	3	4·9
Distance apart of centres of buffers	5	7·3
Body;—		
Total length over cornices	26	0·6
Length outside at top	24	1·4
„ „ bottom	23	5·5
„ inside at waist rails ..	23	8·6
Width outside at top	9	3
Width outside at bottom	8	7·1
„ inside at waist rails ..	8	8·3
Height outside at sides	6	4·8
„ „ centre	6	10·7
„ inside at sides	6	1·2
„ „ centre	6	6·1
Total height of outside of roof above level of rails	10	8·74
Width of doors	1	11·6
Height „	5	9
Length of each compartment between partitions	4	7·9
Space between seats	1	5·7
Axles;—		
Diameter at centre	0	4·72
„ of bearings	0	3·54
Length of bearings	0	7·08

	ft. in.
Distance between centres of bearings	6 4·4
Total length of axle	7 0·9
Weight of each axle	440 lb.
Wheels;—	
Wheel base	14 9·2
Diameter over tread	3 4·9
,, of boss	0 10·04
Length of boss	0 7·9

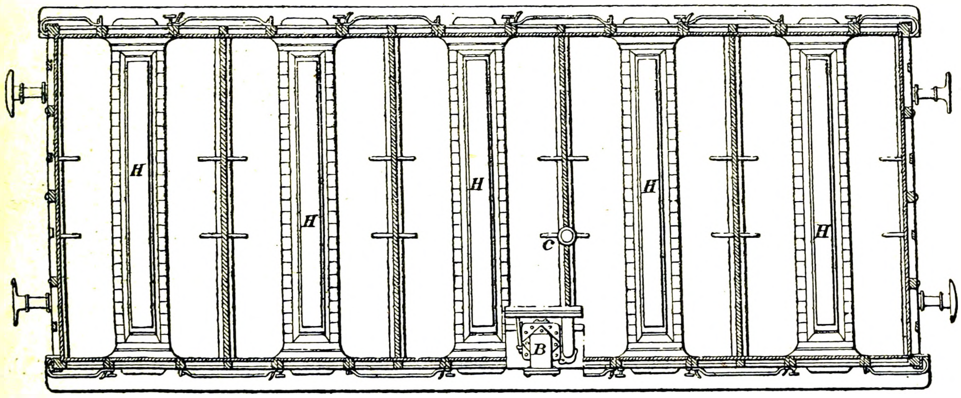
	ft. in.
Width of tire	0 5·1
Normal thickness of tires	0 2·36
Height of flange	0 1
Distance between inner sides of tires	4 5·58
Weight of a wheel without tires	418 lb.
Weight of a pair of wheels with tires and axles	2189 ,,
Weight of an axle box	99 ,,

Springs;—	Bearing.	Draw.	Buffer.
Width of plates	2·95 in.	2·95 in.	2·95 in.
Thickness of plates	0·39 in.	0·39 in.	0·39 in.
Number ,,	10	5	16
Length of top plate between bearing points	4 ft. 7·1 in.	3 ft. 3·4 in.	5 ft. 8·9 in.
Span unloaded	4 ft. 5·3 in.	3 ft. 2·2 in.	5 ft. 4·2 in.
Camber	6 in.	3·9 in.	13 in.
Deflection a ton of load	2·39 in.	1·1 in.	3·3 in.
Weight	114·4 lb.	48·4 lb.	25·6 lb.

Weight of the carriage without heating apparatus	8½ tons
,, heating apparatus	1980 lb.
Dead weight a passenger	3·7 cwt.

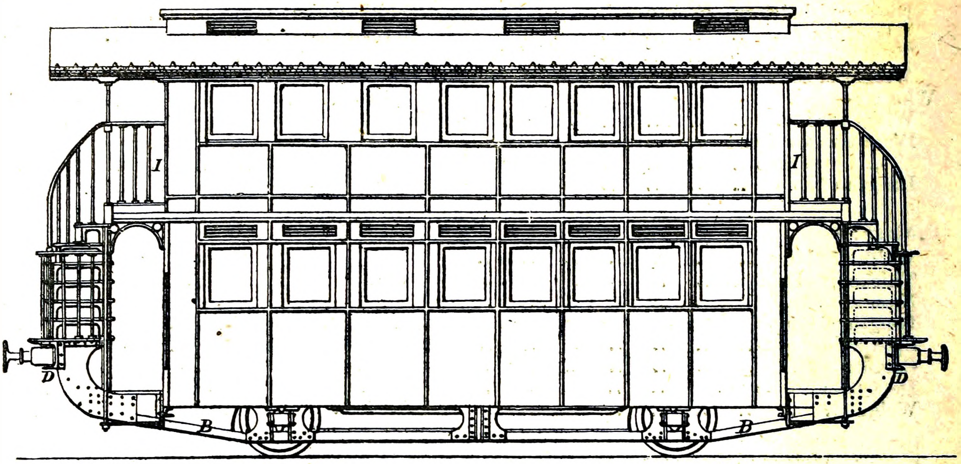
The body of this carriage is divided into five compartments carrying ten passengers each. The central compartment is separated from the others by partitions extending the full height of the body, and is reserved for ladies only; the other compartments being divided by half partitions only. The space available for each passenger in 2 ft. 4 in. long by 1 ft. 9 in. wide. The seats, Fig. 1959, are of a very comfortable shape; the backs being provided with division pieces, which fix the position of the centre passenger on each seat, an arrangement which prevents attempts to occupy the seats by four passengers only. Wooden shelves are fixed in the position occupied by the nettings in carriages of a superior class, and these serve to accommodate small packages. The total interior area of the carriage at the level of the bottoms of the windows is 205·8 sq. ft., while the cubic capacity per passenger is 25·9 cub. ft. The weight of the carriage without the heating apparatus is equal to 374 lb. a passenger, or with the heating apparatus 414 lb. a passenger.

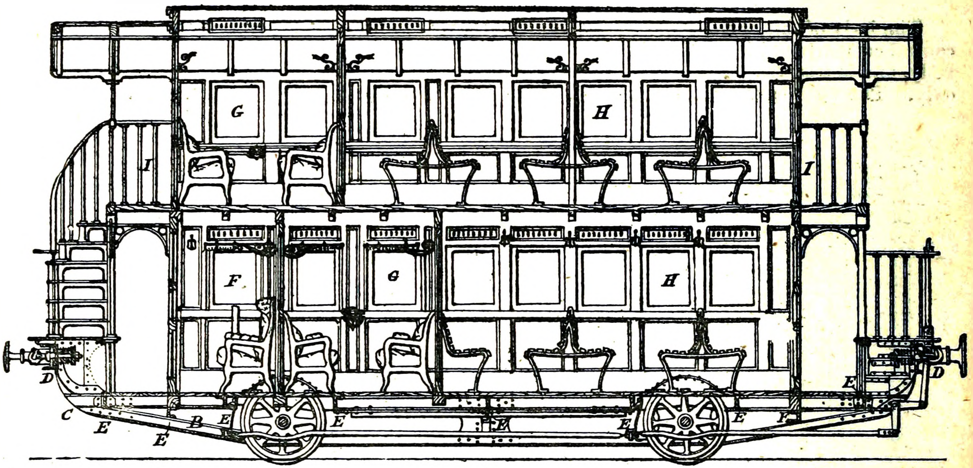
1961.



A two-storied carriage, constructed at the Railway Carriage and Waggon Works, Fribourg, for the Vale of Toess line, in the canton of Zurich, Switzerland; Figs. 1962 to 1965. Fig. 1962 is a side elevation; Fig. 1964 an end elevation; Fig. 1963 a longitudinal section; and Fig. 1965 a cross section, half through the second-class, and half through the third-class compartments on each floor. Carriages of this type are also employed on the Eastern Railway of France; and on the Mountain Railway over the Brünig. The underframe of this carriage is formed entirely of wrought iron, and is kept very low, being curved upwards at the ends, so as to arrive at the normal height of buffers. The side frames are composed of two channel irons, the upper one A, 5·9 in. by 3·15 in., and the lower one B, 3·94 in. by 2·36 in.; these two channel irons being firmly connected by the horn plates, and by a central support to which they are riveted. The upper channel iron of each side frame is straight for its entire length, and at the ends it is met by the lower one, which rises upwards; the two channel irons being connected here by strong end plates C, of the shape Fig. 1963. The transverse connections between the side frames consist of the buffer beams D, which are likewise made of channel irons, and of nine channel irons E, Fig. 1964; the frame being further stiffened by diagonal bracings. The wheels are of wrought iron, made according to Brunon's system, and the axles, tires, and springs are of Krupp steel.

1962.





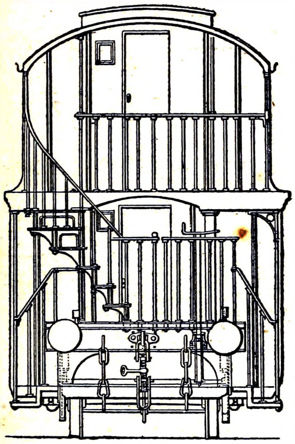
1963.

Each carriage is provided with an efficient screw brake, which can be manipulated from one of the end platforms. The principal dimensions of this carriage are ;—

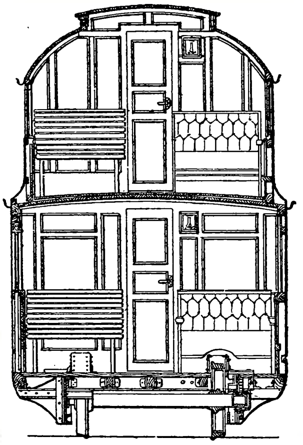
	ft.	in.
Total length of body	21	$7\frac{7}{8}$
,, ,, of roof	30	$0\frac{5}{8}$
,, ,, between buffers	32	$10\frac{7}{8}$
Width between centres of buffers ..	5	9
Height from level of rails to centre of buffers	3	$5\frac{1}{3}$
Total outside width	10	$2\frac{1}{4}$
,, height above level of rails ..	15	$6\frac{1}{4}$
Length of end platforms and balconies, each	1	$11\frac{3}{5}$
Length of steps	1	$11\frac{3}{5}$
Rise of steps	0	8
Diameter of wheels	2	$7\frac{1}{2}$
Distance between wheel centres	13	$9\frac{1}{3}$
Lower story ;—		
Height of floor above level of rails ..	2	$3\frac{1}{8}$
,, from floor to underside of roof at centre	6	$2\frac{1}{3}$
Width outside	9	$8\frac{1}{8}$
Width inside	9	$1\frac{1}{2}$
,, of door	1	$10\frac{1}{2}$
Height ,, ...	5	$10\frac{3}{4}$
Length of first-class compartment ..	3	$6\frac{1}{8}$
,, second-class ,, ..	5	$3\frac{3}{4}$
,, third-class ,, ..	11	$11\frac{1}{3}$
Upper story ;—		
Height of floor above level of rails	8	9
,, from floor to underside of roof at centre	6	$8\frac{3}{4}$
Height from floor to underside of roof at sides	4	10
Width outside	8	$8\frac{1}{3}$
,, inside	8	4
,, ,, of raised portion of roof	4	2
,, of door	1	8
Height ,, ...	5	$10\frac{3}{4}$
Length of second-class compartment	5	$6\frac{1}{8}$
,, third-class ,,	15	$5\frac{1}{2}$

This carriage is divided into a first-class compartment F on the lower story, two second-class compartments G, and two third-class H, one on each story; and provides seating accommodation, including two seats on the upper balconies I, for sixty-six passengers. The seats in the first and second-class compartments are upholstered in Utrecht velvet, those of the third-class being formed of polished wood railings, fastened to light angle-iron frames, which are shaped according to the form of the body. Sliding ventilators are provided above each of the windows in the lower story, and in the sides of the raised portion of the roof of the upper story. The warming is effected by a small transportable heating stove, which is placed in the lower story, after removing some of the seats; and from this stove the chimney leads off to the upper story, where it passes along the roof. The weight of this carriage, when empty, is 10 tons, equal to a dead weight of 3 cwt. a passenger.

1964.

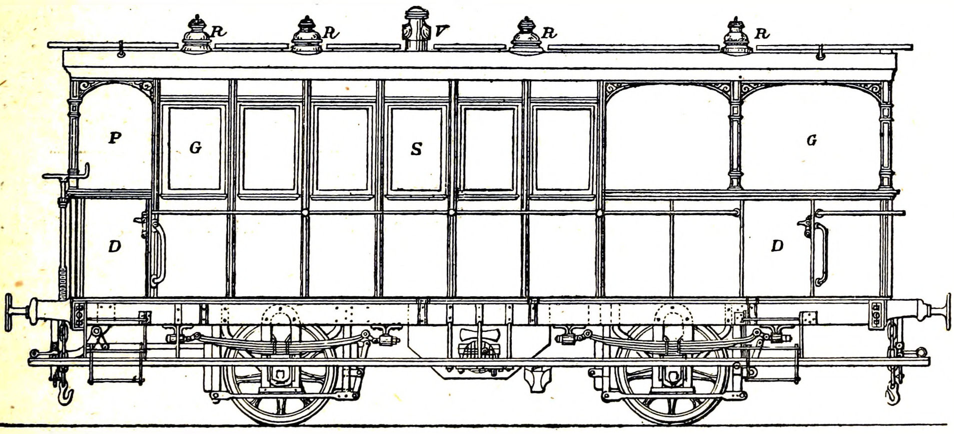


1965.



Saloon and Sleeping Carriages.—Figs. 1966 to 1969; Fig. 1966 is a side elevation, Fig. 1967 a longitudinal section, Fig. 1968 a cross section, and Fig. 1969 a plan of a saloon carriage of the Hungarian State Railways. The underframe of this carriage is of the composite type, the soles being of iron and the rest of the frame of timber. The body, which has a very slight fall under at the sides, projects considerably beyond the soles, and is supported by wrought-iron brackets, as shown in the cross section, Fig. 1968, these brackets having indiarubber pads on their tops; the body, however, rests also on the wooden underframe. The body is 24 ft. $10\frac{5}{8}$ in. long, by 9 ft. wide outside, and 7 ft. $7\frac{3}{4}$ in. high. The wheel base is 12 ft., and all the wheels are fitted with brake blocks on each side. This carriage is warmed by Thamm and Rothmüller's apparatus, and is lighted by four roof lamps R; a ventilator V being also fixed in the centre of the roof of the saloon.

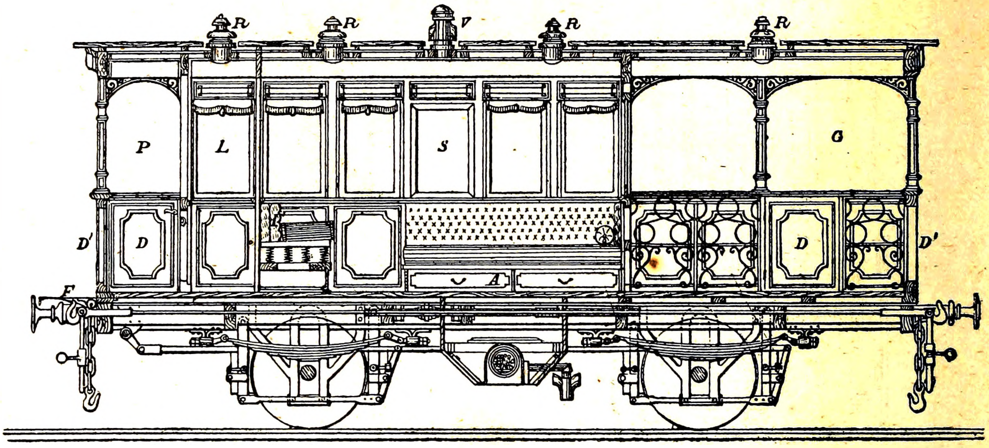
1966.



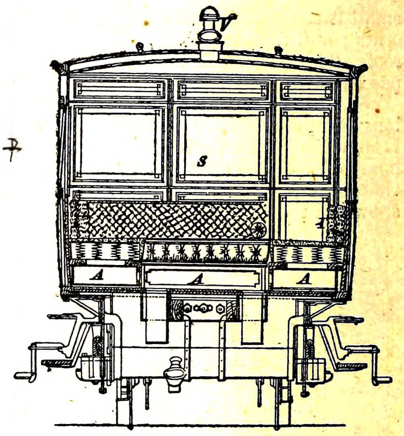
This carriage is divided into an open-sided gallery G, a saloon S, a small lobby L, a lavatory and water-closet C, and a small gallery or end platform P, from which the brake can be worked.

The chief gallery or covered platform G, is 8 ft. $6\frac{3}{8}$ in. long, and is protected by dwarf sides, access to it being given by side doors D, opening inwards; communication with the next carriage is also obtained by means of the folding end-doors D′, the space between the carriages being spanned by a flap F, in the usual way, and the folding doors, which open outwards, forming the side hand-rails. The roof over the gallery G is carried by four cast-iron columns, and curtains are provided to afford shelter from the sun and wind. Around the sides and end of this gallery are arranged seats E, of thin sheet iron pierced so as to imitate canework, while at the end a folding table is provided. The roof of the gallery is lined with American maple, with a border of rosewood. From the gallery G access is obtained by a central door to the saloon S, which is 13 ft. in length. The seats I in this saloon are disposed as shown in the plan, Fig. 1969; the back cushions of these seats, I′, Figs. 1967 and 1968, being formed by mattresses folded up, and these mattresses when unfolded and laid down, convert the seats into very comfortable beds; while beneath the seats are commodious drawers A, in which bed linen, can be stowed. The roof of the saloon is lined in a similar way to that of the open gallery, the lining of the sides being of mahogany, inlaid with maple and rosewood. The seats are upholstered with silk rep of a warm drab tint, and the curtains are of *gros de Naples* of a similar colour. A door gives access from the saloon to a small lobby L, from which two other doors open, one to the lavatory C, and the other to the small end platform P. The lavatory C is furnished with a washstand and the usual fittings, while from beneath the washstand a water-closet draws out; water being obtained from a tank which can be supplied from the roof. The small end platform P is protected by dwarf sides, and is provided, like the end gallery G, with side doors D opening inwards and with folding doors D′ at the end for giving access to the next carriage. In connection with the side doors of both the galleries G and P folding footsteps are provided, as shown in the cross section, Fig. 1968..

1967.

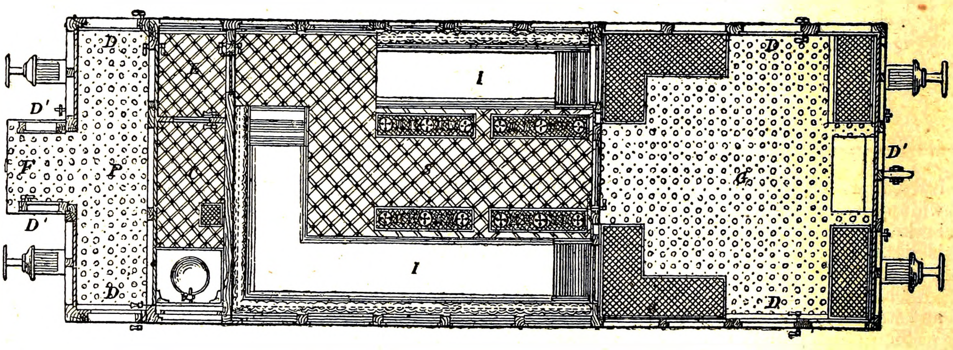


1968.



In Figs. 1970 to 1972 is shown a hunting carriage, or *Jagdwagen*, constructed for the use of the Emperor of Austria, at the works of the Southern Railway of Austria, from the designs of J. and J. G. Hardy Fig. 1970 is a longitudinal section; Fig. 1972 a half cross section and half end elevation; and Fig. 1971 a plan.

1969.



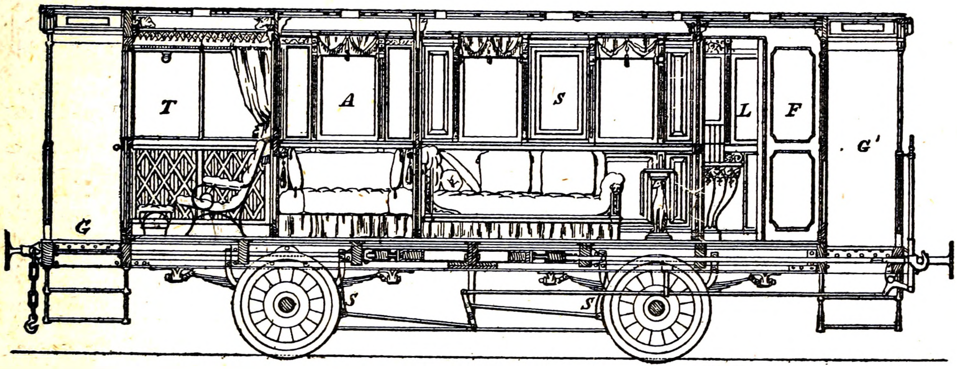
The principal dimensions of this carriage are;—

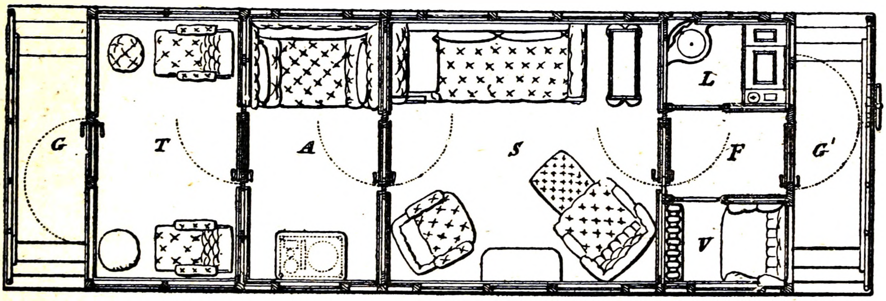
	ft.	in.
Length of body over all	28	10½
„ „ exclusive of end galleries	23	7½
Total length over buffers	32	5⅘
Width of body outside	9	3¾
„ „ inside	8	10⅜
„ of end galleries	6	1¾
Total outside width over lamps	10	9
Height of body inside at centre	7	4½
„ „ „ sides	6	10

	ft.	in.
Wheel base	12	5⅝
Height above level of rails to centre of buffers	3	5
Height above level of rails of floor of end galleries	3	10
Height above level of rails of floor of saloon, &c.	3	11¼
Height above level of rails to centre of roof, outside	11	6¾

The underframe is of iron and wood in combination; the soles being of iron of channel section, placed with the flanges outwards, as shown in the cross section, Fig. 1972, and the rest of the frame of timber. The carriage is fitted with a brake applied to both pairs of wheels, this brake being worked from one of the end galleries G′. The brake blocks are of cast iron, and are hung from their centres, while they are kept steady when out of contact with the wheels, by means of springs S attached to them in the manner shown. The floor is double, and rests directly on the underframes, the body being thus principally carried by the floor and the floor framing. The body is made with vertical sides; the framing being of timber, with the exception of the intermediate side pillars in the end compartment, or verandah, which are of iron; and the panels also are of iron. Access is gained to the carriage by end doors opening on to the end galleries G G′, these galleries being made narrower than the width of the carriage, so as to enable steps to be provided on each side without extending beyond the width of the body. The roof extends over the end galleries, being supported by light iron columns, which also form pillars for the handrails by which the galleries are protected.

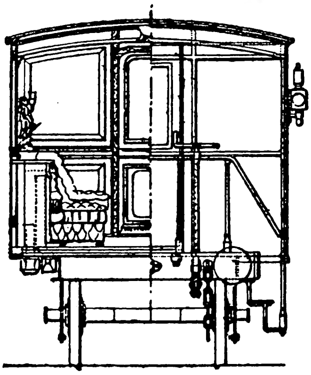
1970.





1971.

1972.

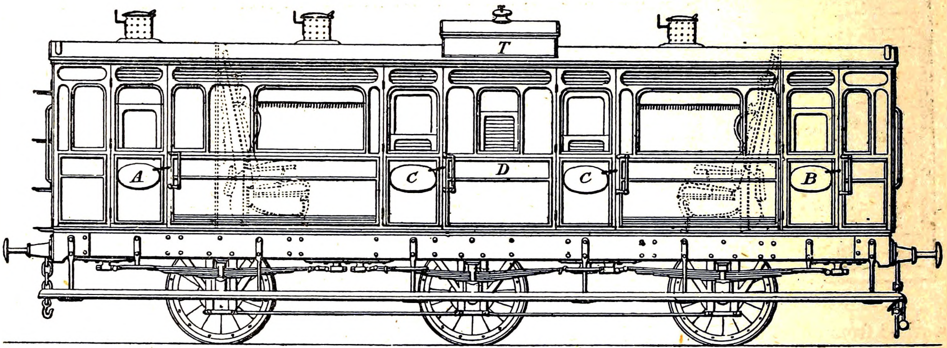


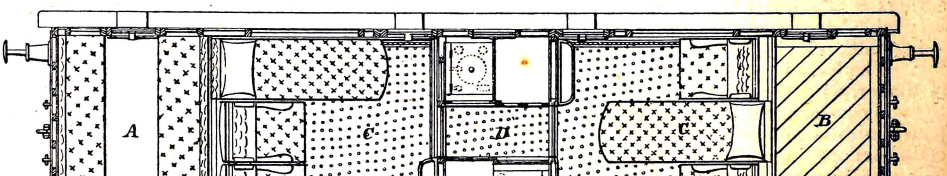
The general arrangement of the interior of this carriage is as follows;—There is first an open gallery G, then a compartment T, forming a kind of closed verandah, as it is called, 5 ft. 1 in. long. The intermediate side pillars of this compartment are of iron; the sash frames at both the sides and end being of brass, so as to render it possible to make them of very small dimensions, and thus give a large area of glass with a very small obstruction to the view; and this verandah thus forms a most pleasant compartment for observing the beautiful scenery traversed by the railway to which the carriage belongs. This compartment is furnished with a couple of lounging chairs and stools, and is decorated with tapestry work of appropriate design. The woodwork in this compartment is of old oak, specially selected for its toughness and fine grain. The next compartment A, Figs. 1970, 1971, is only 4 ft. $7\frac{1}{8}$ in. long inside, and is devoted to the adjutant or other officer in attendance. The fittings consist of a couch or seat, convertible into a bed, on one side, and on the other a washstand, beneath which is arranged a small stove. The woodwork in this compartment is of oak, and the trimming is of green and black striped silk. From the adjutant's compartment A, a door swinging either way gives free access to the main saloon S, devoted to the emperor. This saloon is 9 ft. $4\frac{1}{4}$ in. long, and its width 8 ft. $10\frac{3}{8}$ in., so that it is really, for a railway carriage, a spacious apartment. The decorations of this saloon are in excellent taste, the mouldings being of walnut and ebony, with handsome carvings, while the ceiling is of elaborate parquetry work. The furniture consists of an ordinary armchair, an armchair with a sliding footstool, a couch, a table, and a stove, this stove being capped with green marble, and surmounted by a timepiece, as in the cross section, Fig. 1971. Beyond the saloon S, a short passage F communicates with the end gallery G′, sliding doors on each side of this passage respectively giving access to a lavatory and water-closet L, and a small compartment V, intended for the accommodation of the emperor's servant or valet; this latter compartment also contains a gun rack and an ice safe. From the end gallery G′ the brake is worked. Externally the carriage is painted dark green, relieved by the imperial arms and monograms, in a lighter tint, and picked out with fine gold lines.

The stoves employed in this carriage are Hardy's briquette stoves, which are constructed to burn a specially prepared artificial fuel; and these stoves have been found to give excellent results in practice.

The fuel which is burnt in these stoves consists of briquettes formed of 80 per cent. of pulverized charcoal, and 1·5 per cent. of nitre, held together by a composition composed mainly of lime. The dimensions of these briquettes are $3\frac{1}{2}$ in. by $2\frac{1}{2}$ in. and 6 in. high. Each pair of briquettes forming one of the six units, of which each stove is usually composed, is contained within a small separate removable casing, consisting of a pair of plate boxes reaching up to one-half the height of each briquette, and perforated on all sides with circular holes; each of these casings being held on a separate shelf fixed in the main internal casing of the stove. These briquettes burn very slowly from top to bottom without flame, like a cigar; each briquette lasting for ten hours with the train running at full speed. To regulate the temperature, a greater or less number of briquettes are employed; and when the external air is at freezing point, a temperature of about 65° Fahr. can be obtained in the carriage by the use of the whole number of twelve.

1973.

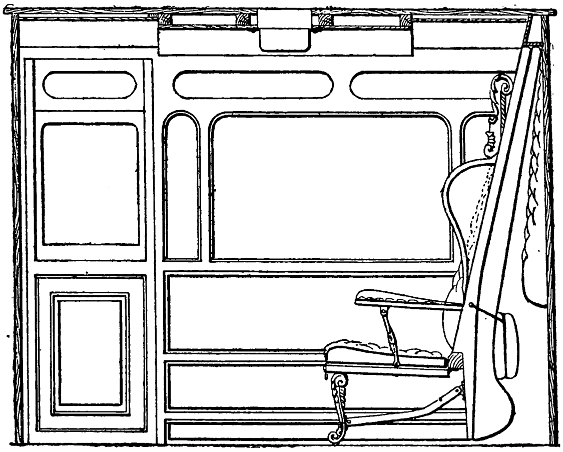




1974.

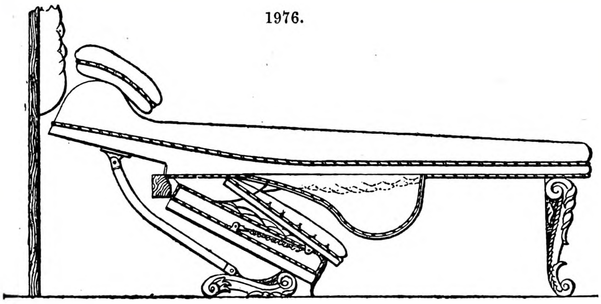
In Figs. 1973 to 1977 is illustrated a sleeping carriage of the London and North British Railway, constructed by the Ashbury Railway Carriage and Iron Company, Manchester, which was the first of its kind built and worked in England; having been introduced on the above line in 1873, in connection with the through trains between London and Edinburgh. Fig. 1973 is a side elevation showing the position of the seats in dotted lines, and Fig. 1974 is a plan showing arrangement of berth; Figs. 1975 to 1977 show the construction and arrangement of the seats and beds to an enlarged scale, Fig. 1975 being a side elevation of seat, Fig. 1976 a side elevation of bed, and Fig. 1977 showing a front elevation of the seats at G, and a front elevation of a bed at H. The whole of the framing and the external panelling of this carriage is of selected Moulmein teak, the soles being strengthened by exterior plates of $\frac{5}{8}$-in. iron; these plates run the entire length and depth of the soles, and all the bolts which secure the axle guards and the other ironwork necessary for the construction of the underframe pass through and are secured to them. The carriage is mounted on three pairs of Mansell's wood-centre wheels 4 ft. in diameter, with wrought-iron bosses and steel tires; and the body is secured to the underframe by bolts, passing through indiarubber body cushions placed between the underframe and the double bottom of the carriage body. The roof is covered with canvas, bedded in white-lead, and painted, and the whole of the exterior of the body and underframe is highly varnished. The dimensions of the body of this carriage are;—Length 30 ft.; breadth 7 ft. 6 in.; the height from the floor to the underside of the centre of the roof being 6 ft. 10 in., and the total height above the surface of the rails about 12 ft.

1975.

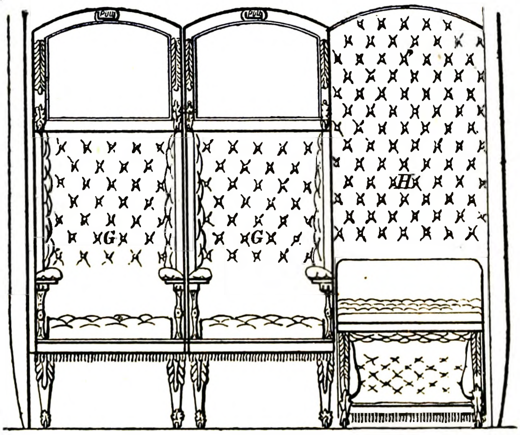


At one end of the carriage is a second-class compartment A, 5 ft. 10 in. long, and at the other a luggage compartment B, 4 ft. long, the central portion being arranged as two first-class saloon compartments C, each 8 ft. 1 in. in length, divided by a lobby D, 4 ft. in length, one side of this lobby being fitted up as a lavatory E, and the other as a water-closet F, both of which are supplied with water from a tank T, carried in the roof; while in the roof is also fixed a filter, from which water is supplied to the lavatory for drinking purposes. The lavatory is furnished with a mirror, a lamp, a marble washing bowl, towels, and other toilet requisites; the water-closet also being fitted with a lamp and other conveniences. The windows of both these compartments are provided with sliding louvre blinds, and the glass is ornamentally obscured. Each of the two first-class compartments C provides sleeping accommodation for three persons, the doors leading into lobby D being provided with locks to prevent through communication when desired. These compartments are elegantly furnished, the sides and roof being panelled with polished silver walnut wood, set with ebony and gold mountings; the whole of the furniture and mountings, both outside and inside are silver plated, and the floors are covered with the best pile carpet laid on kamptulicon; the seats and backs are trimmed with crimson Utrecht velvet on a basis of spring mattress with sofa springs, and stuffed with horsehair. The conversion of the day carriage into a sleeping compartment is a very simple matter: the three seats and their backs, in each compartment are so arranged that on folding the seat up and pulling the back forward, Fig. 1976, which is very easily done, the latter falls down and forms a very comfortable bed 6 ft. 3 in. long, and furnished with a pillow. When no longer required for use as a bed, it is readily lifted into its original position, Fig. 1975, and the compartment resumes its ordinary appearance. Each compartment is provided with a 10-in. roof lamp, which is fitted with a hinged hood to obscure the lights during the hours of sleep. Ventilation is obtained by means of movable louvres and slides, placed both at the bottom and top of the carriage. The woodwork of the second-class compartment A is

1976.



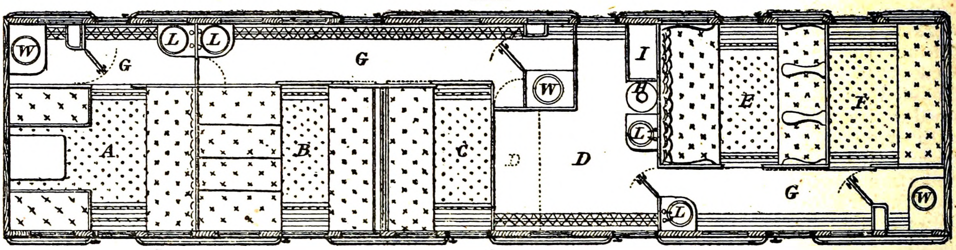
1977.



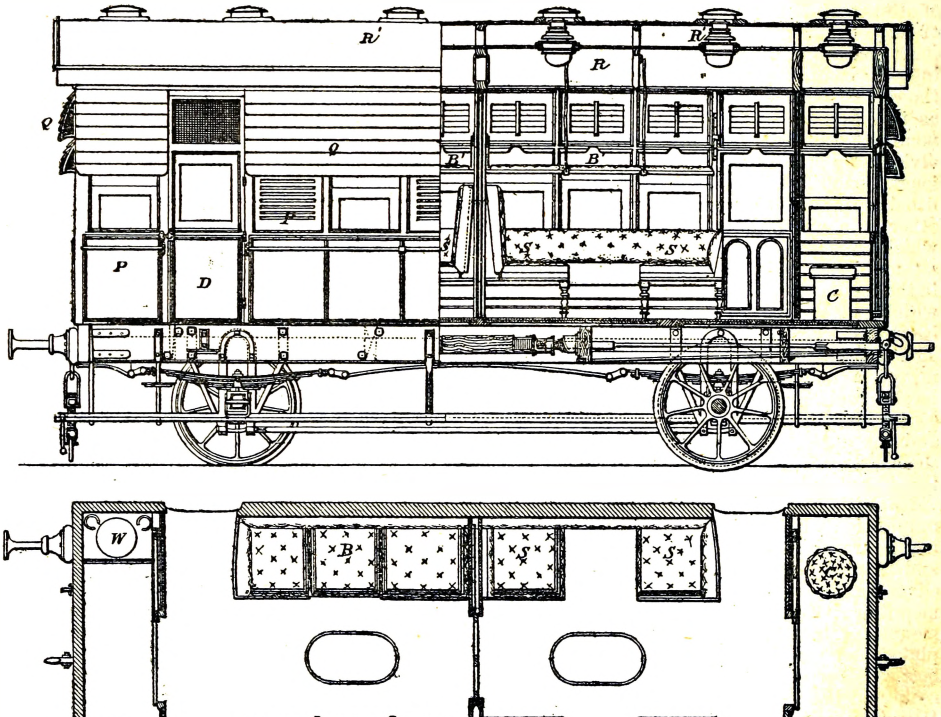
painted and grained oak, the upper portions, above the back-rests, being highly varnished. The seats and back-rests are covered with rep, and stuffed with horsehair, the general arrangement being in keeping with the company's second-class stock.

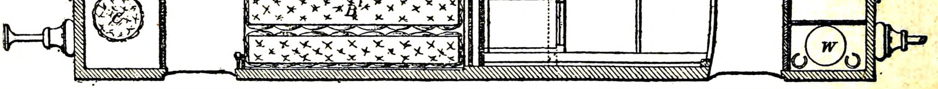
A plan of a sleeping carriage, Fig. 1978, designed by W. D. Mann, for use on English railways, possesses many advantages over the Pullman type of sleeping car, especially as regards privacy. This carriage is 40 ft. in length, 9 ft. in outside width, and weighs about 13 tons, and provides accommodation for twenty-two first-class passengers, besides a central compartment for luggage, warming apparatus, and attendant porter. It is divided into six compartments, A, B, C, D, E, F, with connecting corridors G, in which are placed the lavatories L, and water-closets W. The compartment A is 8 ft. in length, and is arranged as a family boudoir to accommodate six people, in two single and two double berths, with separate water-closet and lavatory. The compartments B and C are arranged to be taken either together or separately; in the latter case the compartment B resembles A, and C is a smaller chamber, containing accomodation for two travellers; these two compartments having one water-closet and lavatory in common. The compartment B is 8 ft., and C 4 ft. 6 in. in length. D is the baggage compartment and place for the attendant; it is 7 ft. long, and contains the heating apparatus H, a coal bunk I with cupboards over, and a sleeping berth at D′ for the attendant porter, this berth being placed 5 ft. 6 in. above the floor. The compartment E, which is 7 ft. in length, is specially adapted for gentlemen travelling alone; it has accommodation for six passengers, the seats being lowered at night to within a short distance of the floor, so as to give greater space for the two upper tiers of beds.

1978.



1979.

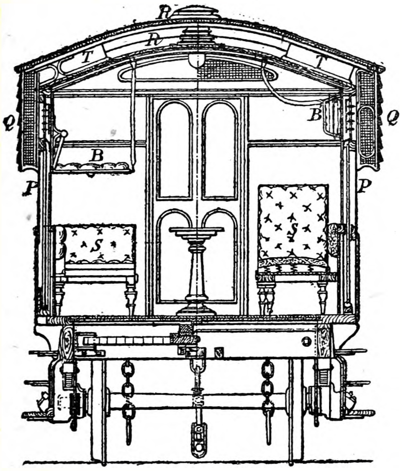




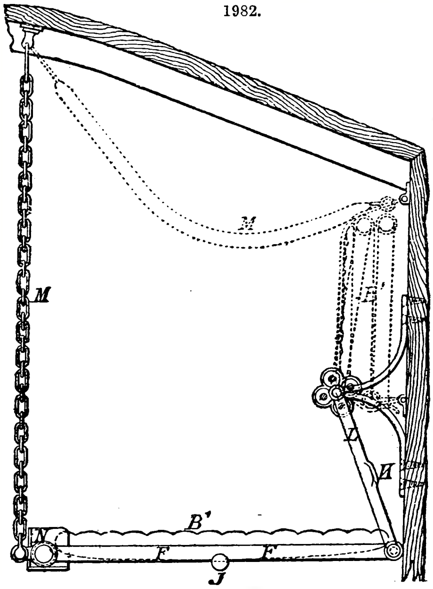
1980.

Lastly, there is a small boudoir F, 5 ft. long, for two passengers, with upper and lower single berths; there is one water-closet common to these two compartments. Through communication is provided for the attendant to each compartment by the corridors G, which are 2 ft. 6 in. wide, while means are adopted to make each perfectly distinct from the other, the communicating doors being opened only by a pass-key in the possession of the attendant. This carriage is thus adapted to meet the varied requirements of persons travelling alone, or in large or small parties; while, from the ample accommodation it affords, as compared to weight of vehicle, it leaves little to be desired in this respect. The floors, sides, and roofs are double, the spaces between the sides and floor being packed with sawdust or other suitable material to deaden sound, and to keep the carriage cool in summer and warm in winter, while the double covering of the roof serves the same end. With regard to the means of ventilation, double windows are provided, the outer ones of which can be removed in the summer, when frames filled with fine wire gauze, which admits air while it excludes dust, take their place. Ample ventilation is also secured by the raised central part of the roof, which occupies about one-third of the width, and is elevated about 16 or 18 in. above the roof itself; the sides of this raised portion being fitted with swinging windows protected with gauze, so that when they are opened a thorough current of air is always maintained.

1981.



1982.



A sleeping carriage of the East Indian Railway, Figs. 1979 to 1984, which is employed on the through service between Calcutta, Bombay, and Lahore, in the construction possesses several novel features; Fig. 1979 is partly a side elevation and partly a longitudinal section, Fig. 1981 is a cross section, and Fig. 1980 a plan of the interior arrangements. This carriage was built, and all the fittings made, at the Calcutta terminus of the East Indian Railway, under the direction of R. W. Pearce; its weight, including 7 cwt. of water in tanks, is 9 tons.

The principal dimensions are;—

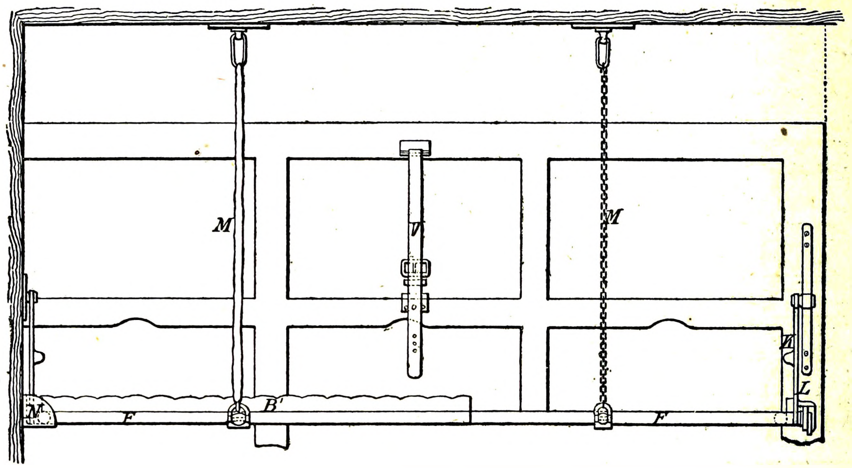
	ft.	in.
Length of body outside	23	2
„ „ inside	22	7
„ of outer roof	24	8
„ of each sleeping compartment	8	$10\frac{1}{8}$
Width of body, outside	9	0
„ „ inside	8	2
Height from floor to underside of inner roof at centre	7	10

	ft.	in.
Height from floor to underside of upper bed	4	$2\frac{1}{2}$
Air space between inner and outer roof	0	$7\frac{3}{4}$
Distance between wheel centres ..	14	0
Diameter of wheels	3	6
Total outside width	10	6
„ height above level of rails ..	13	6

Dimensions of frame timbers, 12 in. by 4 in.

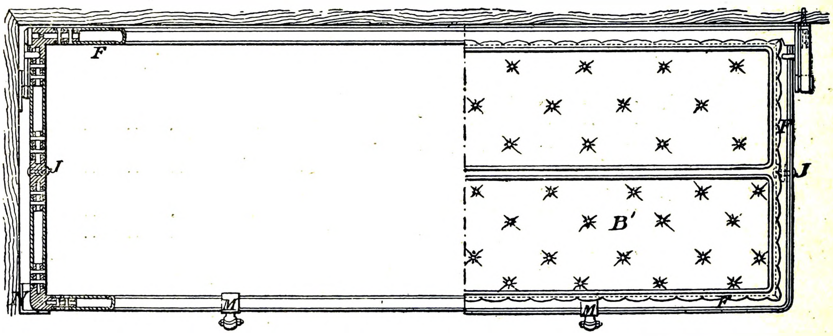
The whole of the timber used in the construction of this carriage is Moulmein teak. The outside lower panels are of iron $\frac{1}{16}$ in. thick, this being the only material really found to stand the climate. These panels are put on in rebates from the outside and well screwed all round to the framing, a half-round moulding covering the screw heads; this mode of securing being very neat, and adding greatly to the strength of the framing. When using wood on the East Indian Railway, wide panels were found to buckle in the rains, and shrink out of the grooves in hot weather, and to split up if secured by screws; by using very narrow panels, these defects were of course lessened to some extent, but never entirely removed. In adopting iron it was at first thought that this material would conduct or radiate heat to a greater extent than timber, but after a series of experiments this was found not to be the case, while by properly securing, in the manner above described, and not having the sheets too large, the iron has been found to run with just as little noise as wood. The glass frames of doors and windows are all balanced, and to counteract any tendency to rise or fall with the motion of the train, they are each fitted with two adjusting screws with milled heads; the passengers can, therefore, secure the frame permanently at any desired height. To keep out glare and heat as much as possible, coloured plate glass, No. 9 B.W.G. in thickness, has been adopted in lieu of plain plate, the colour chosen being a bluish green, this having been found from the average of a series of 40 registrations to be the best; the colours experimented with, and the average temperatures for the 40 registrations, being;—Bluish green 106° F., violet 111°, red 112°, yellow 114°, and white 118°. The water tanks T placed between the inner and outer roofs R R′, contain 40 gallons each, or 80 gallons in all, and are connected by suitable piping to the wash-basins W and commodes C. The outer roof R′ is on the most improved plan, affording the best protection from the direct rays of the sun, and is connected with the side sunshades and extended down to a height of 1 ft. 7 in. from the window rails, thus becoming one huge saddle-back enveloping the roof and sides of carriage, with a clear air space of 7 in. between the two. The end openings of the sunshade Q are filled in with wire gauze, 114 meshes to the square inch, as a protection from sparks, coal, or dust, from the engine. The space between the sunshade Q and side of carriage P is further rendered a complete air tunnel by the following means; pieces of painted canvas, or leather, are stretched over the side door openings D, and are secured to a bracket on the shutting pillar on the one side, and to the sunshade on the other or hinge side of the door, the canvas thus folding up and allowing the door to open and shut freely. The outside painting is white, with a bluish tint picked out brown. The sunshades are green, and the inside varnished teak; the roof neutral tint, the floor drab, and the cushions green morocco.

1983.



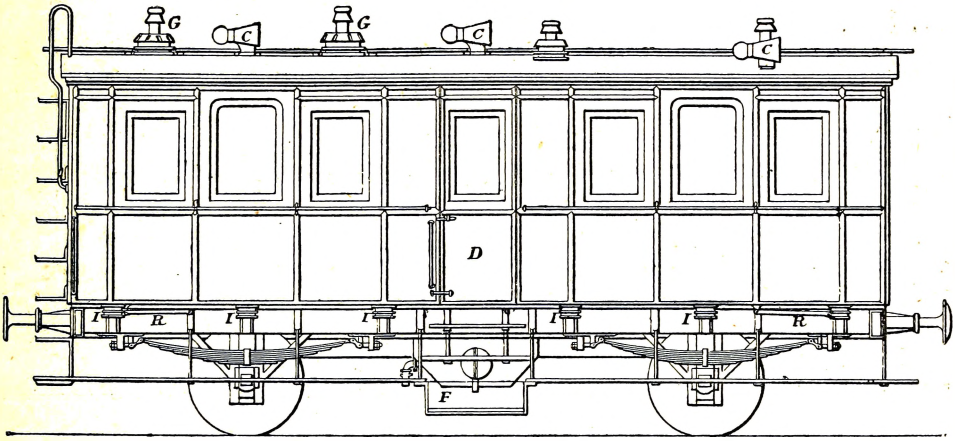
The carriage is divided into two compartments, with separate retiring room to each; these retiring rooms being at each end of the carriage and partly over the buffers, thus utilizing those portions of the carriage which are subject to the greatest amount of lateral oscillation, and reserving for passengers the central part, which is least liable to motion. These compartments can be rendered quite separate by closing the sliding door in the centre, which can be fastened on either side, or when desired the whole can be thrown open as one grand saloon. This carriage accommodates only eight sleeping passengers, four to each compartment, and this is found to be as many as can conveniently travel together in the hot climate of India. The seats S are longitudinal, and are arranged to slide on rollers and legs with castors, to enable the passengers to ride with their faces, backs, or sides to the engine, as may be wished, or to form a convenient longitudinal couch as at B. The upper sleeping berths B′ were designed by Richard Pearce, assistant carriage superintendent of the East Indian Railway, and are shown to an enlarged scale in Figs. 1982 to 1984; Fig. 1982

1984.

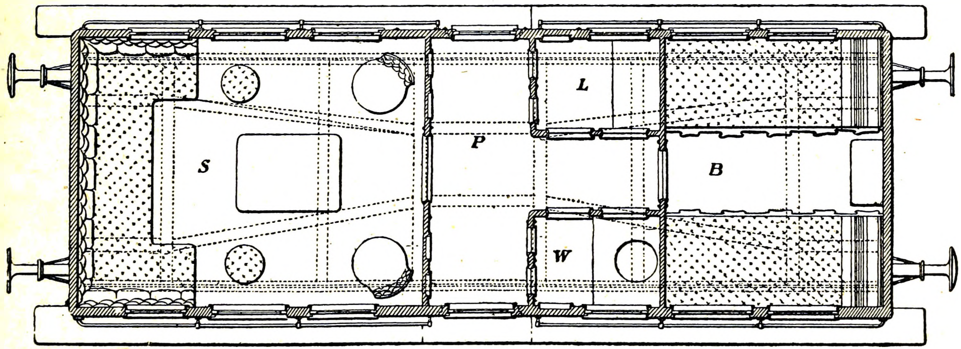


being an end elevation, Fig. 1983 a side elevation, and Fig. 1984 a part plan of bed and part plan of framing, one end of the latter being in section in order to show the method of joining. The frame F is made of $1\frac{1}{4}$-in. gas-piping, and folds up knapsack fashion, and entirely out of the way when not required for sleeping or night use, as shown by the dotted lines in Fig. 1982, in which position it is secured by the strap V. The gas-piping forms an exceedingly neat frame, about half the weight of ordinary wood ones, and possessing great strength. The frame is jointed into two halves longitudinally by knuckle or rule joints J; the cushion is in halves also, and is supported on canvas stretched tight across the iron frame, thus forming a perfectly easy and elastic bed, somewhat resembling a ship's hammock. The bed, when lowered into position, rests on a brass stop plate N, and is supported by the chains M, these latter being covered with leather. To prevent the lever L, or side of bed, from turning over the wrong way, a catch K is provided in the said lever.

1985.



1986.



A saloon and sleeping carriage of the Kaiserin Elizabeth Railway, constructed at the Bubua Waggon Works, Prague, and which is intended especially for the accommodation of the Empress of Austria, is shown in Figs. 1985 and 1986; Fig. 1985 being a side elevation, and Fig. 1986 a plan.

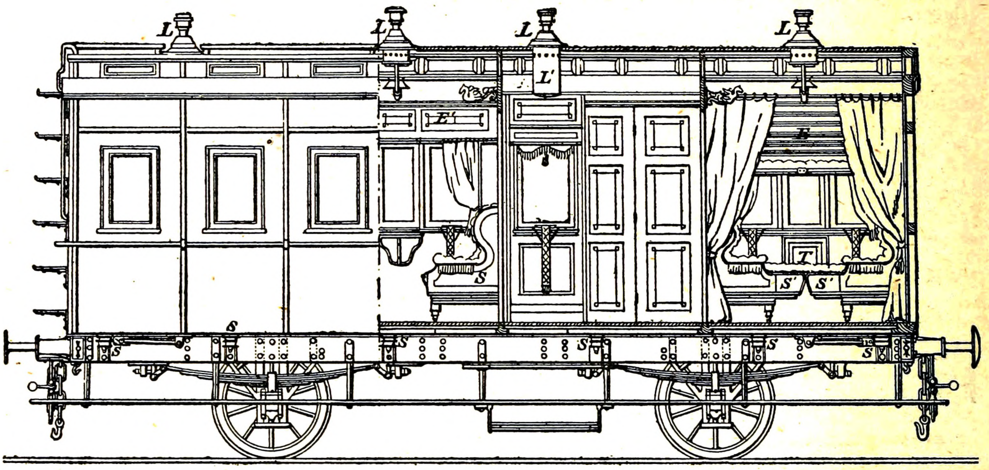
The principal dimensions of this carriage are as follows;—

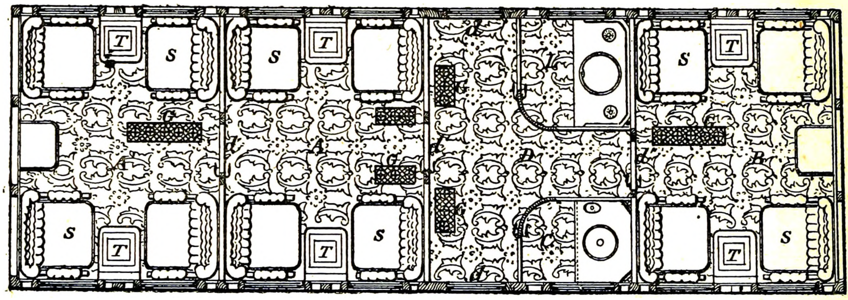
	ft.	in.		ft.	in.
Length of body outside	24	$1\frac{3}{8}$	Total width over all	10	0
Width " "	8	$6\frac{3}{4}$	" height above level of rails ..	12	9
Height " at sides	6	7	Width inside	8	$0\frac{3}{8}$
" " at centre	7	$5\frac{7}{8}$	Length " of saloon	10	2
Wheel base	13	$5\frac{7}{8}$	" " of sleeping compartment	6	6
Total length over buffers	27	8	Total length inside	23	$3\frac{3}{8}$

The frame is of composite construction, the soles being of I iron, $9\frac{5}{16}$ deep, and placed 6 ft. $7\frac{13}{16}$ in. apart from centre to centre, while the rest of the frame is of wood. The wheels are of solid wrought iron, and the bearing springs are long. The draw-bar is continuous, and is provided with an indiarubber draw-spring, the buffer springs being also of indiarubber. In the front of the doors there are provided footsteps F, which may be raised or lowered, these steps being necessary to afford easy access to the carriage, as the stations on the Austrian railways are without platforms. Between the body and the underframe there are interposed twelve indiarubber cushion springs I, which are carried by cast-iron brackets bolted to the soles, while end or transverse motion of the body on the frame is checked by means of radius bars R. The floor of the body is strongly framed, and is composed of two layers of planking laid with crossed joints, and glued together, whilst above this planking is fixed the parquetry work which forms the floor proper. The roof of the carriage is made double, the roof-sticks being arranged between the inner and outer planking. The ventilation of the carriage is secured by providing each compartment with ventilators communicating with air-collecting cowls C, on the roof.

The general arrangement of this carriage is as follows;—A door D, on each side of the carriage gives access to a central transverse passage or lobby P, having a clear width of 2 ft. 11¼ in. On one side of this passage a door opens into the saloon S, while on the other side are the lavatory L and water-closet W; a short longitudinal passage, 2 ft. 3 in. wide in the clear, being led off between the two last-mentioned compartments, and giving access to the sleeping compartment B. The saloon S is richly trimmed with a light drab silk rep, the mouldings being white and gold. The fittings consist of a couch, extending across one end, a couple of chairs, a couple of round stools, and a table which unfolds and forms a mirror; mirrors being also placed on the door and on the walls. The floor of the saloon is covered by a carpet, and the compartment is lighted by two large roof lamps G. The communicating passages P, together with the water-closet W, and lavatory L, are panelled with parquetry work, with mahogany and gilt cornices; and the floors, as also that of the sleeping compartment A, are carpeted. The lavatory and water-closet doors are made in two leaves to save room, these leaves being connected so that they open and close simultaneously. Beneath the wash-hand basin in the lavatory is fixed an ice safe for the storage of provisions. The sleeping compartment B contains two sleeping couches, arranged against the sides of the carriage, there being a passage a little over 3 ft. between them. This compartment is trimmed with dark green silk rep.

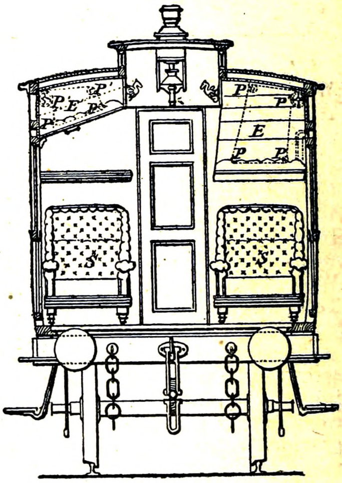
1987.





1988.

1989.

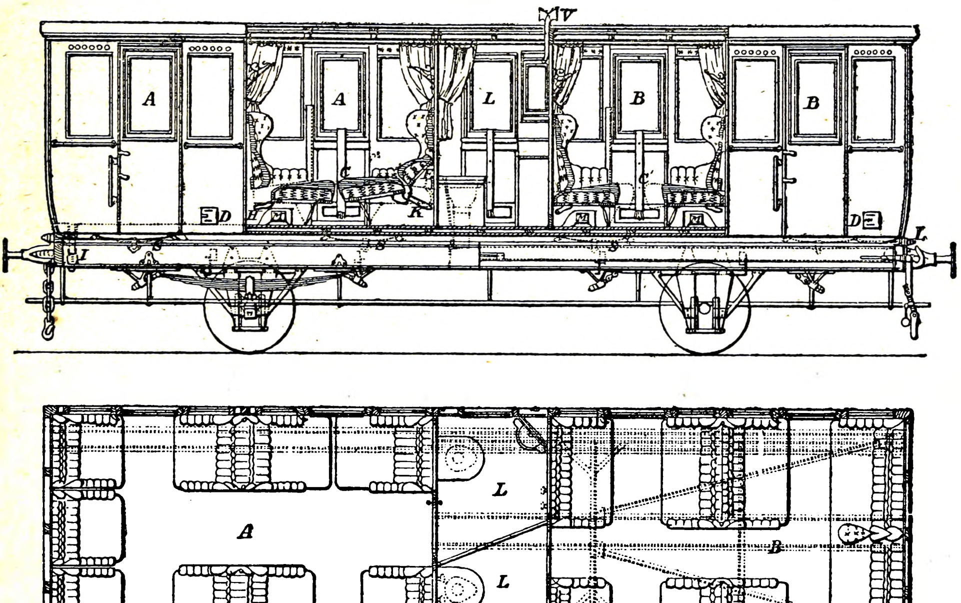


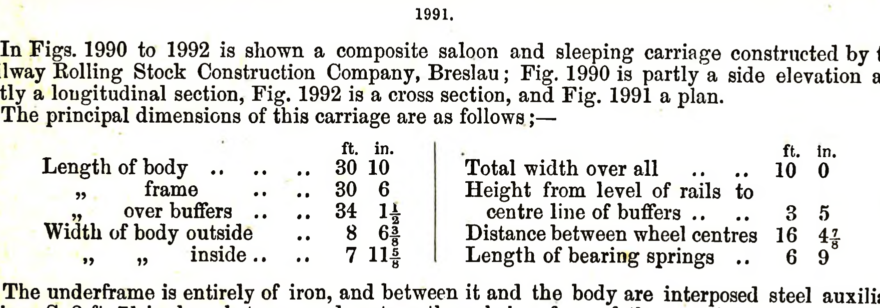
In Figs. 1987 to 1989 is shown a sleeping carriage constructed at the railway carriage and waggon works, Simmering, near Vienna; Fig. 1987 is partly a side elevation and partly a longitudinal section, Fig. 1989 is a cross section, and Fig. 1988 a plan. The underframe of this carriage is of a composite construction, similar to the saloon carriage illustrated in Figs. 1966 and 1967. The body is carried on indiarubber cushion springs S, its outside dimensions being as follows;—length 25 ft. 11 in., width 8 ft. 6⅜ in., height 8 ft. 8⅜ in., wheel base 13 ft. 5⅞ in., and the weight of carriage 11½ tons.

The roof is raised in the centre, and in this raised portion are hung the lamps L, one to each compartment, these lamps being fitted with ventilating arrangements, and also provided with shades as shown at L′ for obscuring the light at night. The lining of the carriage is of mahogany, inlaid with rosewood and maple, the floor being of well executed parquetry work. The colour of the trimmings is a warm drab, the seats being covered with silk rep, and the curtains being of *gros de Naples.* The warming is effected by the heated air being admitted to the several compartments through the gratings G fixed in the floor.

The carriage is divided into three compartments A A′ and B; A A′ being intended for gentlemen, and B for ladies; a lobby D, to which access is gained by side doors *d*, and a lavatory C, and water-closet W; communication being obtained between the several compartments by means of the doors *d′*. Each of the compartments A A′ B contains on each side two seats S, with a table T between them; this table being movable and the seats capable of being drawn out so as to meet and form a bed as shown at S′, Fig. 1987, the upper parts of the backs of the seats being removable so as to be used as pillows. Above each pair of seats is a second bed E, which, when out of use, occupies the position shown at E′, Figs. 1987 and 1989, its underframe then forming part of the ceiling. When required for use each of these upper beds is drawn down into the position shown at E, where it is supported on suitable fixed ledges. In this position it is 4 ft. 8 in. above the floor, or sufficiently high to clear the heads of people sitting on the seats beneath it. Each upper bed E E′ is provided at each end of its frame with a couple of small brass pulleys P, over which, and over pulleys P′ fixed to the partitions, there passes a suspending cord formed of covered copper wire, this cord being capable of sustaining a load of 6 cwt. The pulley P′ fixed next the side of the carriage is, it will be seen, larger than the others, and it is double, the two ends of the cord passing over it, and being attached to a counterbalance weight running in a suitable casing in the side of the carriage; this weight being such that the bed is perfectly balanced in each position, and it can thus be raised or lowered with great ease, and when closed up it is secured by a lock and key. Above each of the upper beds, when raised, there is a space which provides stowage room for the mattress of the lower bed. Curtains are provided for shutting off the beds from the central passage, and there are also small ladders or portable steps for giving convenient access to the upper beds.

1990.





1991.

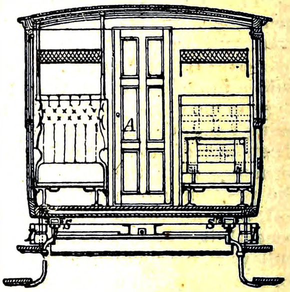
In Figs. 1990 to 1992 is shown a composite saloon and sleeping carriage constructed by the Railway Rolling Stock Construction Company, Breslau; Fig. 1990 is partly a side elevation and partly a longitudinal section, Fig. 1992 is a cross section, and Fig. 1991 a plan.

The principal dimensions of this carriage are as follows;—

	ft.	in.		ft.	in.
Length of body	30	10	Total width over all	10	0
" frame	30	6	Height from level of rails to centre line of buffers	3	5
" over buffers	34	1½	Distance between wheel centres	16	4⅞
Width of body outside ..	8	6⅜	Length of bearing springs ..	6	9
" " inside	7	11⅝			

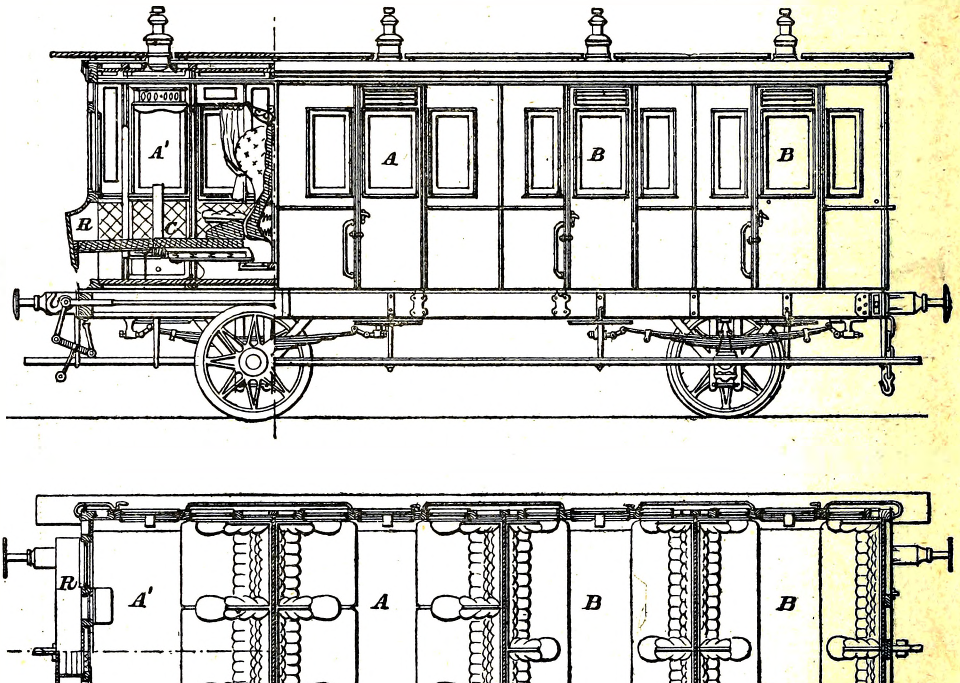
The underframe is entirely of iron, and between it and the body are interposed steel auxiliary springs S, 2 ft. 7½ in. long between end centres, there being four of these springs on each side of the carriage; they are placed directly over the soles, upon which they bear, and their ends are coupled by links to angle irons, of which a pair extend longitudinally under the body on each side for its whole length. End motion of the body on the underframe is prevented by means of radius links L, situated at the four corners, and pulling against indiarubber pads, while too great freedom vertically is prevented by leather straps I, attached to the corners of the body, and connected to pins pulling against very thick indiarubber rings, which have a bearing against brackets fixed to the underframe. The draw-bar is continuous; the buffer and draw-springs being volutes, and the buffers having wrought-iron skeleton casings. The panels of the carriage are of iron. Besides the longitudinal angle irons already mentioned as supporting the auxiliary springs S, the body frame is further stiffened by bottom cross bars of ⊤ iron filled in with wood, alternating with cross bars of wood only. The roof and floor are double. For balancing the window sashes of the doors, an arrangement of counterweights is provided, the counterweights being connected to a bar, on which the sash rests when partially open or when lowered, this bar serving also, when in its highest position, to close the well in which the sash runs. The standing pillars are furnished with the finger guards very generally used on German railways, these guards each consisting of a strip of stiff leather, fixed so as to overlap the joints. The doors also have strips of indiarubber let into dovetail grooves in their framing, these strips closing against similar strips let into the body framing. A ventilator is provided over each fixed side light, and the lavatories have ventilating cowls V, in the roof.

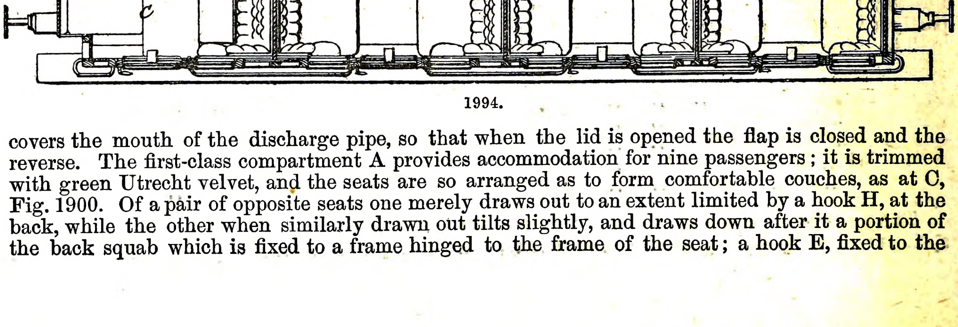
1992.



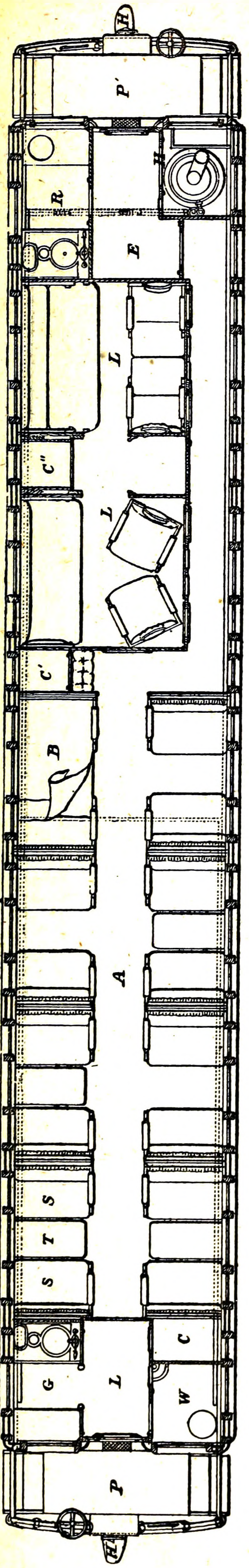
The carriage is divided into two double compartments A B, having between them a central space, which is divided by a diagonal partition so as to form two unequal-sized lavatories L, each containing a water-closet. The lid of each water-closet is connected by a link with the flap which covers the mouth of the discharge pipe, so that when the lid is opened the flap is closed and the reverse. The first-class compartment A provides accommodation for nine passengers; it is trimmed with green Utrecht velvet, and the seats are so arranged as to form comfortable couches, as at C, Fig. 1900. Of a pair of opposite seats one merely draws out to an extent limited by a hook H, at the back, while the other when similarly drawn out tilts slightly, and draws down after it a portion of the back squab which is fixed to a frame hinged to the frame of the seat; a hook E, fixed to the

1993.





1994.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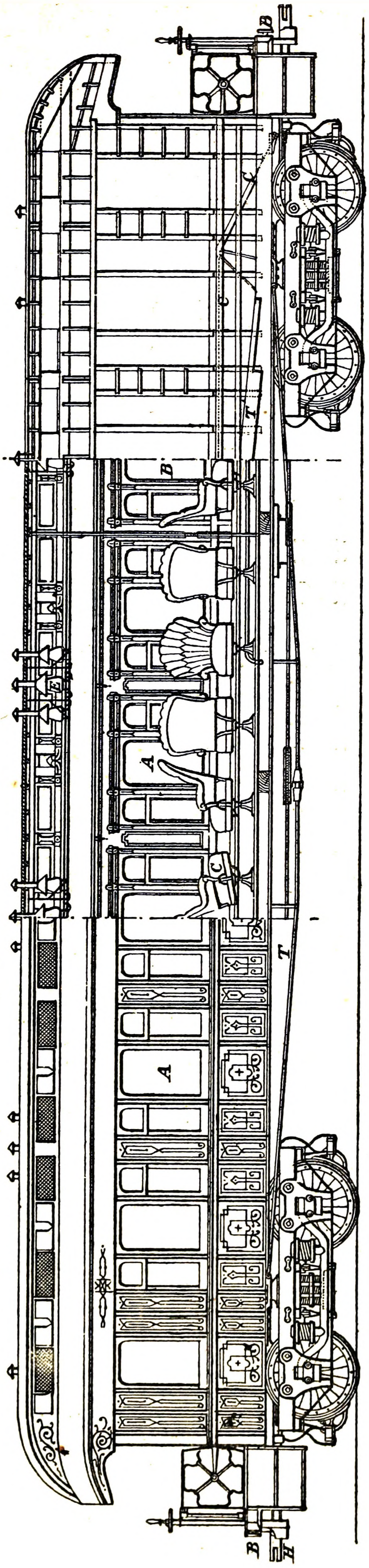
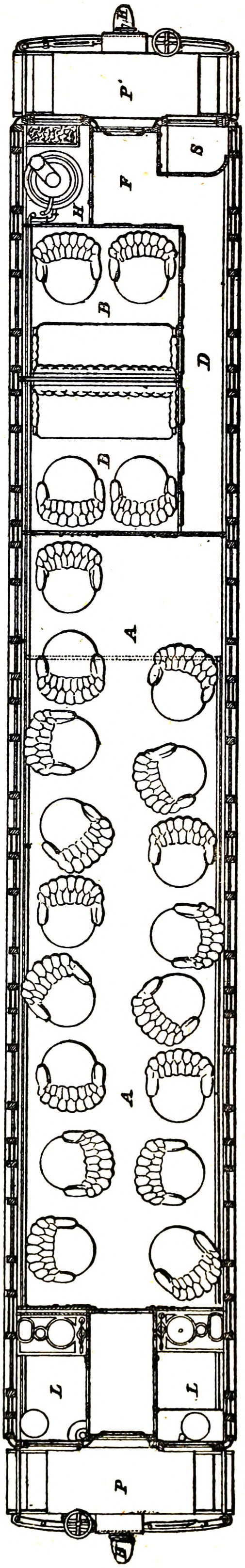
1995.


B
H
C
T
B'
E
A
C
A
T
B
H

1996.


H
P'
S
F
H
B
D
D
A
A
L
L
P
H

1997.

partition limits the descent of the squab, while a link K controls the drawing out and tilting of the seat. The second-class compartment B accommodates thirteen passengers, it is trimmed with drab cloth, and the seats simply draw out, as shown by the dotted lines at C′, Fig. 1990. The carriage is warmed by briquettes placed in suitable iron casings M arranged under the seats; the doors for inserting these briquettes being shown at D.

The weight of this carriage, when empty, is 11 tons 10 cwt., or a dead weight of about 11½ cwt. a passenger.

A second type of continental composite carriage, constructed for the northern lines of the Austrian State Railways by F. Ringhoffer, of Smichow, near Prague, is shown in Fig. 1993 in side elevation, and in section through the coupé, and in Fig. 1994 in plan. This carriage is mounted on a composite frame, the soles being of I iron, and the rest of the frame of wood. The outside panels also are of iron; and the roof of the carriage double.

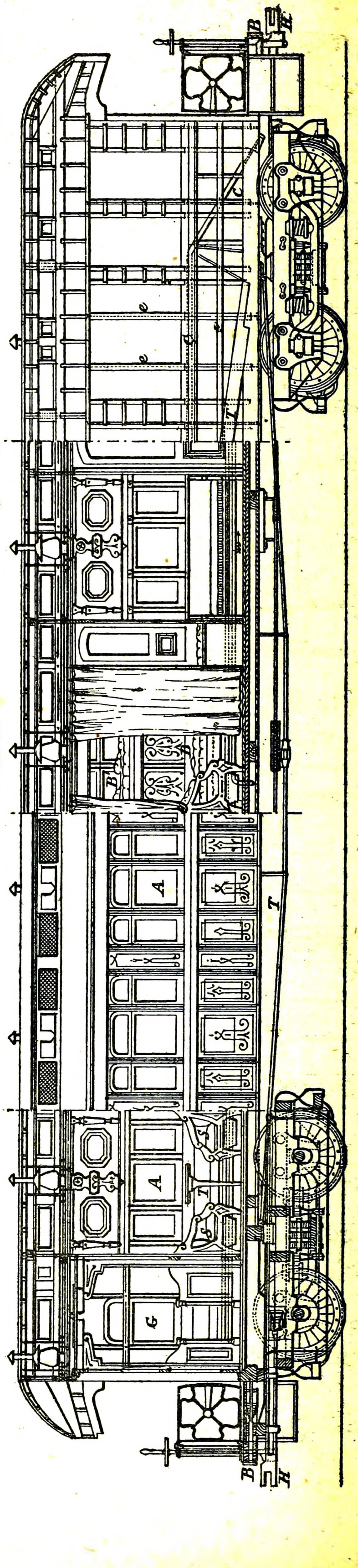
The principal dimensions are as follows;—

	ft.	in.
Length of body outside, exclusive of projection of coupé	24	4½
Length of frame	24	7
Width of body outside	7	7⅝
„ over all	9	4
Height inside at centre	6	5¼
Length inside of coupé	5	3¾
„ „ of first-class compartment	7	0
Length inside of each second-class compartment	5	6⅝
Distance apart of soles between centres	6	4
Length of bearing springs between centres of eyes	6	2⅝
Wheel base	14	6¼
Height from level of rails to centre line of buffers	3	5½

The weight of the carriage empty is 8 tons 15 cwt., or a dead weight of 7 cwt. a passenger.

The body is divided into four compartments, two first-class A, and two second-class B; one of the first-class compartments A′ being a coupé, accommodating three passengers, and is fitted with seats affording sleeping accommodation, as shown at C. The end of the carriage at which the coupé is situated, instead of being made flat as usual, projects outwards, below the windows, to the extent of 9⅜ in., a recess R being thus formed into which the lower parts of the beds, or extension of the ordinary seats, can be folded; the recess also accommodating cushions or pillows for the head. In the plan, Fig. 1994, two of the extensions of the seats are shown folded up, whilst the other C is in the horizontal position. The first-class compartment A is fitted up in the ordinary way, and accommodates six passengers; the second-class compartments B, carry eight passengers each; the total number of passengers carried by the vehicle being twenty-five. The first-class compartments are trimmed with crimson Utrecht velvet; the mouldings, being of walnut and maple; and the arms of the seats are made to fold up out of the way when desired. The second-class compartments have the roofs and interior above the cushions lined with oilcloth, and the cushions covered with leather.

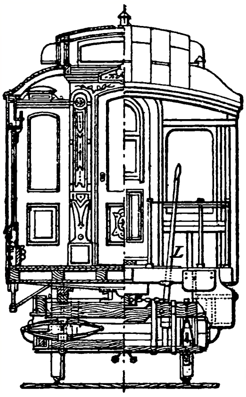
Pullman Cars.—The first of these cars, was constructed by Pullman in 1859, and was run on the Chicago and Alton Railway, between the former place and St. Louis, a distance of about 280 miles. The cars employed upon the English railways differ somewhat from those on the American lines, being carried on


1998.

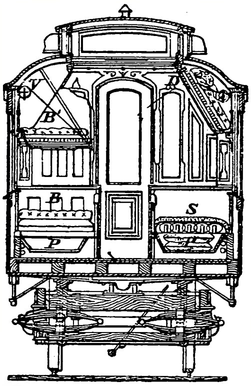
four-wheeled bogie trucks, while the practice in the United States is to employ six-wheeled trucks, the cars so mounted being stated to ride more easily and smoothly than those on the four-wheeled trucks.

Figs. 1995 to 2011 relate to these cars. Fig. 1996 is partly a side elevation, partly a longitudinal section, and partly an elevation of the body framing of the drawing-room car; Fig. 1999 is a half cross section and half end elevation; and Fig. 1997 a plan of the same car. The sleeping car is shown partly in side elevation, partly in longitudinal section, and partly an elevation of the framing in Fig. 1998; in cross section in Fig. 2000; and in plan in Fig. 1995, the end elevation being similar to that of the drawing-room car, shown in Fig. 1999.

1999.



2000.

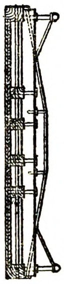


The principal dimensions of these cars are;—

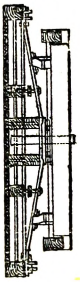
		ft.	in.
Length over end platforms		58	0
Width		9	0
Height above level of rails		12	11
Length of body		51	6
Width „ outside		8	9
„ „ inside		8	2
Height „ outside, at sides		6	10½
„ „ inside, at centre		8	6½
Wheel base of each bogie		6	6
Distance apart of centres of bogies		39	0
Total wheel base		45	6
Length of bogie truck		11	0
Width „		6	10¾
Diameter of wheels		3	6
Length of axles		7	3
Diameter „ at centre		0	4½
„ „ at back of wheel		0	5⅛
„ „ at wheel seat		0	5
„ journals		0	3½
Length of „		0	8
Distance between centres of journals		6	6
Radius from bolster pin to centres of rubbing pieces J		2	5⅝
Principal timbers of bogie frame	4 in. by 7 in.		
Longitudinals F and N	3 „ 10¼ „		
Car Framing;—			
Total length of framing		57	0
Length of framing of body		52	0
Width of „		8	7
Soles	5 in. by 7 in.		
Longitudinals	4 „ 5½ „		
Cross timbers *t′*	4½ „ 7 „		
„ „ *t*	2 „ 5½ „		

The construction of the body framing of these cars will be readily understood from the elevations, Figs. 1996 and 1998, and the plans and sections, Figs. 2001 to 2004, and from the following description. Fig. 2001 is a half plan of the under side of the bottom framing; Fig. 2002 a longitudinal section of the same; Fig. 2003 a cross section on the line *a b*; and Fig. 2004 a similar section on the line *c d*.

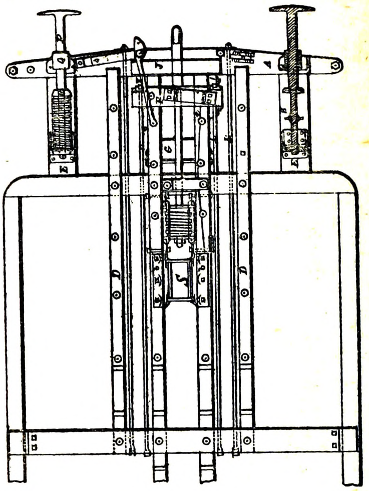
The floor framing consists of four longitudinal timbers, besides the sole-bars, these longitudinals and the sole-bars being connected at short intervals by transverse timbers *t*, and resistance to oblique strains being given by a double flooring, the planking of which is laid diagonally. The sole-bars are strengthened by truss-rods T, and at four points between the bogie centres there are also transverse bearers *t′*, which are stiffened by double truss-rods. The sole-bars between the



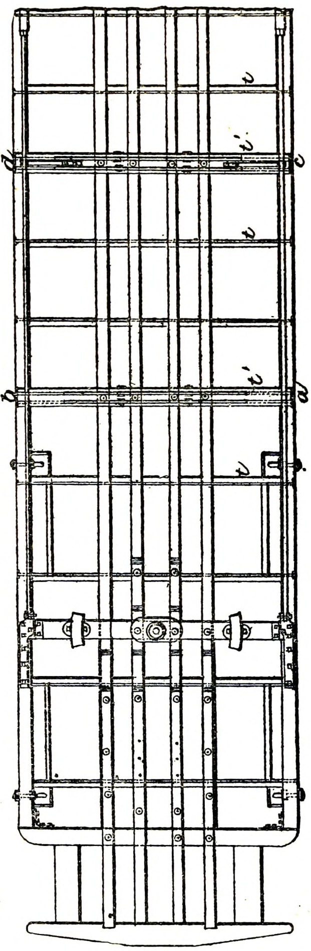
2003.



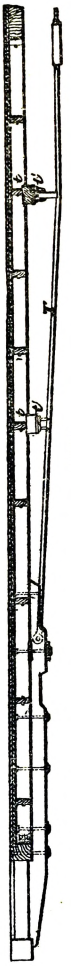
2004.



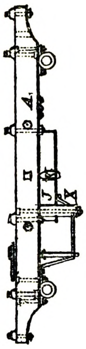
2005.



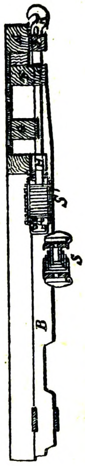
2001.



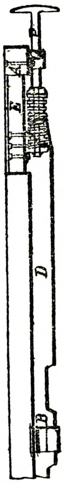
2002.



2007.



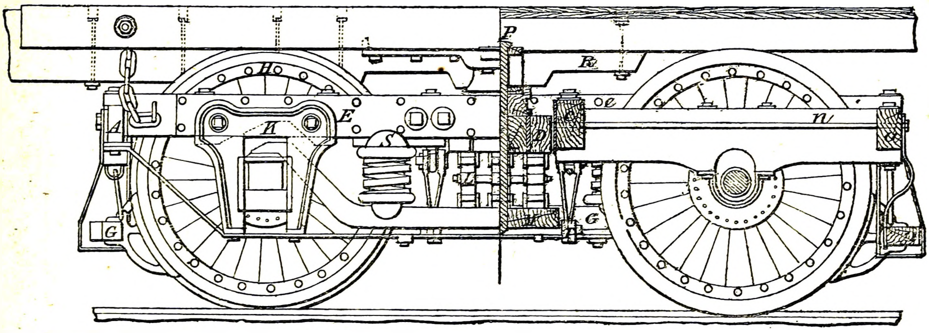
2008.



2006.

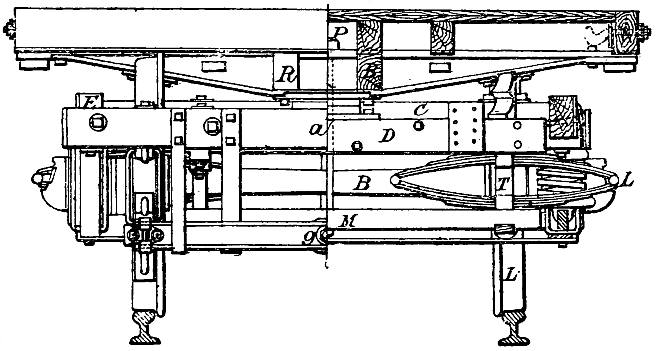
bogie centres are strengthened not only by the truss-rods T, but also by diagonal timbers and straining beams, which form a regular truss beneath the windows. Besides this, a tie-rod or counter-brace C extends along each side under the windows, this tie-rod bearing upon cast-iron struts fixed on the sole-bars in a line with the bogie centres, and then extending obliquely down through the soles so as to give support to the ends of the car, and keep all parts of the trussed framing well up to their work. It will thus be seen that the floor, combined with the trussed sole-bars and the body framing beneath the windows, really constitute a kind of girder of ⊢⊣ section, and form a structure possessing great powers of resistance to either compressive or transverse strains. The upper part of the body framing consists of vertical pillars of apparently light section, a number of these pillars being, however, strengthened by wrought-iron rods *e* extending through them from top to bottom, as shown by dotted lines in Fig. 1998. An appearance of great lightness is thus obtained without a sacrifice of strength. The central portion of the roof of each car, as shown in Figs. 1999 and 2000, is considerably higher than the rest, and to avoid the necessity of carrying roof-sticks across this raised part, T iron is largely used in the roof framing, the T iron roof-sticks following the contour of the roof.

2009.



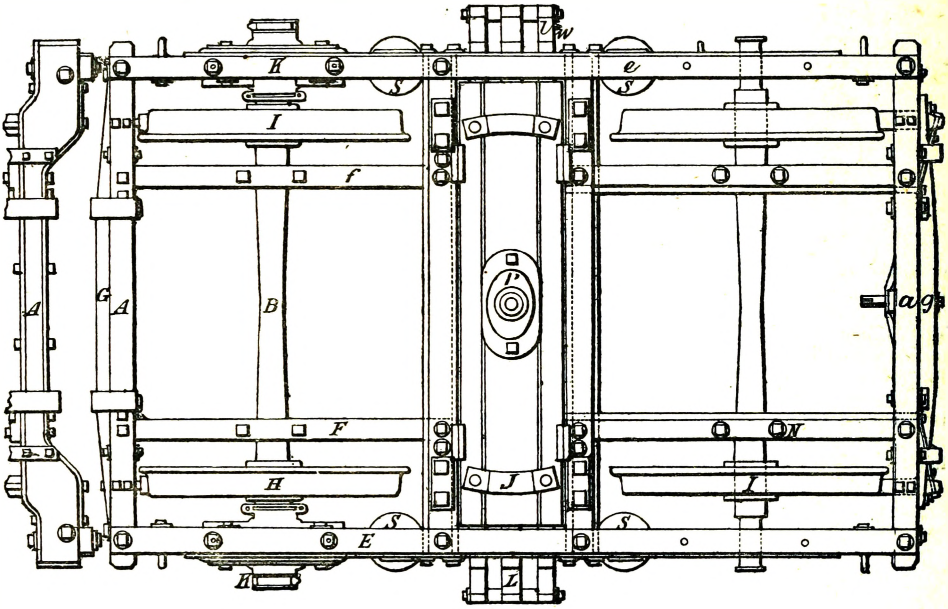
The cars are fitted with central buffers and couplings, the end platforms and the couplings being arranged on Miller's system, which is in extended use in the United States. In this arrangement the compressive strains are received by central buffers B, Fig. 2008, placed above the coupling hook H, these buffers transmitting the strain direct to the framing. The coupling hooks H are formed on the ends of bars of cruciform section, and are connected to draw-springs fixed to the two central longitudinal timbers of the floor framing, the connection being such that the outer end of the hook is free to move horizontally to a small extent, although its tendency is to remain in a central position. The ends of the hooks H are so formed that when two cars are brought together the hooks at first push each other aside, until the cars having come sufficiently close the hooks engage each other, the operation of coupling thus being automatic. When the cars are coupled the buffers B are somewhat compressed, so that there is no slack. To uncouple the cars one of the hooks H is drawn aside by the hand lever L, Fig. 1999, which is connected to the hook-bar by a chain, while by pulling the lever L over into a notch, the hooks can, if desired, be kept from engaging with each other when the cars are brought together. In the case of these cars, however, it has also been necessary to provide for their being in some instances coupled up with stock having the ordinary side buffers, and for this purpose the arrangement in Figs. 2005 to 2008 has been designed, Fig. 2005 being a plan of the underside of end of bottom framing, Fig. 2006 a side elevation, Fig. 2007 an end elevation, and Fig. 2008 a longitudinal section of the same. On reference to these drawings it will be seen that the side buffers P′ and central draw-hook K′ can at any time be very readily removed, the latter being replaced by the buffer B, while the hook H can be connected to the spring S, specially provided for it. The alteration of the car from the side to the central buffing system, or the reverse, being thus an operation requiring only a few minutes for its performance.

2010.



Figs. 2009 to 2011 are detail views of the construction of the trucks or bogies on which these cars are mounted. Fig. 2009 is a half longitudinal section and half side elevation; Fig. 2010 a half end elevation and half cross section; and Fig. 2011 a plan. These trucks are four-wheeled, and are fitted with wooden disc wheels 3 ft. 6 in. in diam. The bolster body is connected to the truck by a central pin P, and takes its bearing partly on the plates surrounding this pin and partly on the side rubbing pieces J. The weight of the body is thus transferred to the beam D, between which and the swing beam M, are interposed the bearing springs L, there being three of these springs on each side. The beams D and M, together with the springs L are free to swing laterally, the beam M taking its bearing on the pins which connect the lower ends of the links T on each side. By the links T the swing beam M is suspended from the side frames E, and these, in their turn, bear upon spiral springs S, which are interposed between their under sides and the upper sides of the bent bars B, the ends of these latter resting upon the axle boxes; the load being thus transmitted to the axles through two series of springs.

2011.



The interior of this car, Figs. 1996, 1999, is divided into a main saloon A, 30 ft. long; two private compartments B, each 6 ft. long; and some smaller compartments forming lavatories. Commencing at the end P, Fig. 1997, it will be seen that access to the interior of the car is afforded by a central door opening into a short passage provided with another door at its inner end. On one side of this passage is the gentlemen's lavatory L, and on the other side that for ladies L′. From this passage access is gained to the main saloon A, which contains seventeen chairs. The chairs are of a very comfortable shape, and are each mounted on a central standard so that they can be turned almost completely round, their motion being only limited in the direction of the central passage, which it is desired to keep clear; while by drawing a bolt each chair is left free to be canted backwards into the position C, Fig. 1996. From the end of the main saloon a passage D leads along one side of the car, past the two private compartments B, doors opening from this passage giving access to these compartments, each of which contains a seat or sofa, and two chairs similar to those in the main saloon. Beyond these private compartments is a kind of lobby F, having on one side a small compartment H, containing the heating apparatus, and on the other a store closet S; a door from this lobby opening on to the end platform P′. In the internal fittings of these cars no expense has been spared to add to the comfort of the passengers. The seats, which are very comfortable, are upholstered with Utrecht velvet, the floor is well carpeted, and the interior is well lighted by handsome lamps E, arranged as in Fig. 1996. The lining panels are of American walnut relieved by gilt chamfers, which contrast well with the colour of the wood. The windows are large and well fitted, and are provided with blinds made of a peculiar material finished off with stamped leather. These blinds are mounted on rollers fitted with a very neat little contrivance for holding them in any position, and which, unlike such contrivances in general, does not seem likely to get out of order. It consists simply of an elliptical cam fixed to the roller, and pressed upon by a spring, the result being that at two points in each revolution the roller tends to stick; the material of the blinds being sufficiently rigid to impart motion to the roller, and to move it past the sticking points when the blind is pushed up. With the exception of the lamps, and the hat-rail brackets, which are bronzed, the metal work within the car, such as the door handles, and the like, is almost all nickel plated. The water for the lavatories is contained in tanks beneath the basins, a small pump beside each basin raising the water as required; this arrangement being adopted to avoid the employment of roof tanks, which are difficult to fill. Each lavatory also contains a special cistern containing a supply of drinking water.

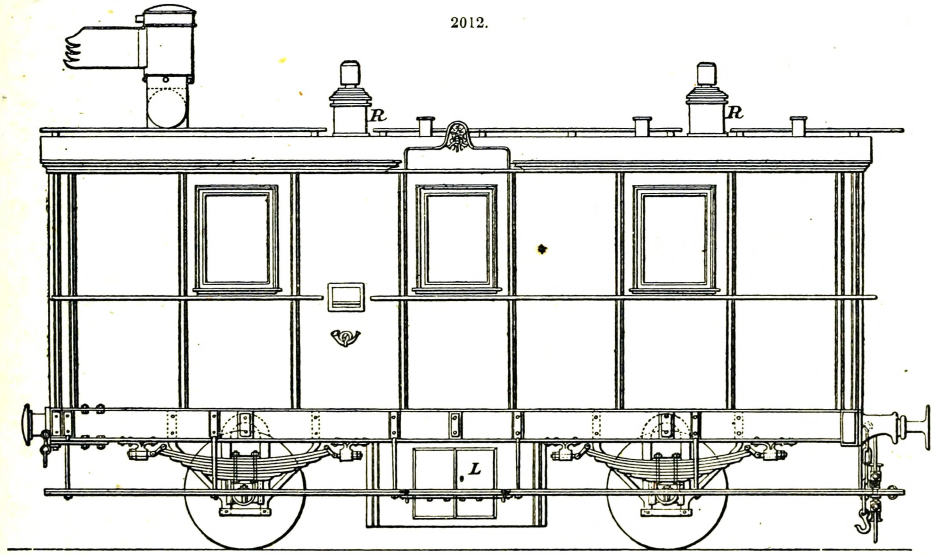
The internal arrangements of the sleeping car, Figs. 1995, 1998, are as follows. Entering from the platform P we pass through a passage L, 5 ft. long, having on one side a gentleman's lavatory G; and a water-closet W, and linen closet C, on the other. At the inner end of the passage is a door opening into the main compartment A, which is 25 ft. 9 in. long inside and is traversed by a central aisle from end to end. On each side of this aisle there are, during the day, four pairs of seats S, with a table T between the seats of each pair. For night service the tables T are removed, and each pair of opposite seats S converted into a bed B; while a second bed B′ is formed above them. To form the bed B, the seats S are drawn out, and the backs then fall down and fill up the spaces left by the withdrawal of the seats. A mattress is then placed over the seats, and in this way a very comfortable bed is obtained. The arrangement of the upper tier of beds is shown in Fig. 1998, and in the cross section, Fig. 2000. During the day the shelves containing these beds are folded up obliquely against the roof of the car, as shown at D; whilst when required for use they are drawn down as shown at B′. The beds B′ are balanced by connecting the shelves by a chain to a coiled spring V, the spring being coiled up as the bed is pulled down, and the reverse; and can thus be pulled down or pushed up very easily. When down they are at such a height above the floor that passengers can, if they desire it, still occupy the seats beneath them. The seats S are each of sufficient length to accommodate two passengers, and the beds are nominally double beds; they are, however, rarely occupied by more than one passenger each. The mattress and bed linen for the lower bed B is, during the day time, stowed away upon the upper one B′, while a box below the seat receives the pillows, as at P, Fig. 2000. At the end of the main compartment A is a second linen closet C′; while beyond are two private compartments L, which are entered from a passage which runs along one side of the car; and between these compartments is a third linen closet C″. Each of the private compartments L contains a couch, which can be drawn forward at night so as to form a comfortable double bed; there is also an upper berth, and two seats which are also convertible into a bed. Beyond the private compartments is a lobby E, having on one side a ladies' lavatory and dressing-room R, and on the other a small compartment containing the heating apparatus H; a door opening from this lobby giving access to the end platform P′. The seats, as in the drawing-room car, are upholstered with Utrecht velvet; all the internal woodwork being of American walnut, relieved by gilt chamfers.

The warming of these cars is effected by hot-water pipes led off from warming apparatus contained in the compartment H already mentioned. This apparatus consists of a small heating furnace or stove containing a coil of piping; the water heated in this coil passing up to a tank on the roof, and from thence being led off through the pipes which pass along the sides of the carriages below the windows; a return pipe bringing it back, when cool, to the heating coil. The water thus circulates constantly, while the small tank on the roof serves to contain a reserve supply which will make up any slight losses due to evaporation or leakage.

The ventilation is provided for by the windows, by openings at the sides of the raised portion of the roof, and by air inlets in the under sides of the hoods which protect the end platforms. These air inlets, as well as the other roof openings, being protected by fine wire gauze, so as to avoid severe draughts, and prevent the entrance of dust and cinders.

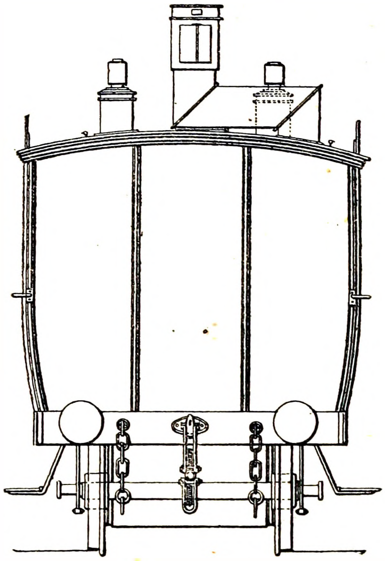
Each of these cars is fitted with the Westinghouse air brake; the brake blocks, which are of cast iron, being applied to all the wheels.

2012.

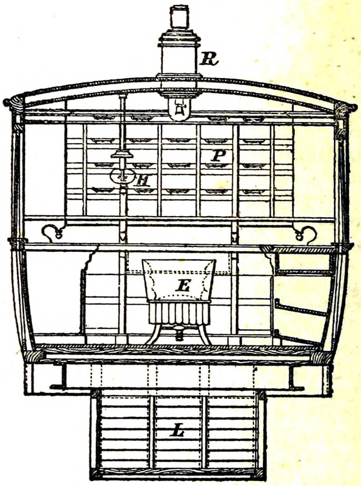


Post Office Vans.—In Figs. 2012 to 2021 are shown the Post Office vans constructed for the Austrian Mail Service, by the Railway Carriage and Waggon Company, Simmering, near Vienna. These consist of a travelling Post Office, Figs. 2012 to 2016, fitted with complete accommodation for sorting letters, and a tender, Figs. 2017 to 2021, constructed to carry the mails in bulk, and parcels. These two vehicles communicate by end doors D′, and an intermediate platform which is

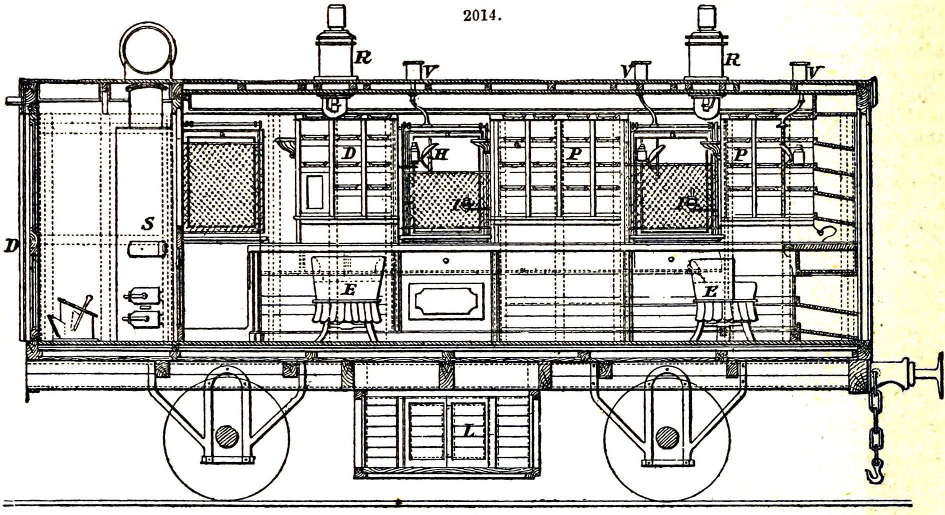
2013.

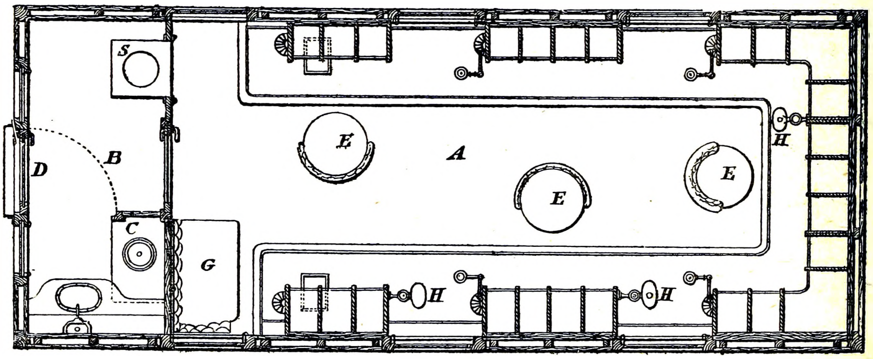


2015.



2014.

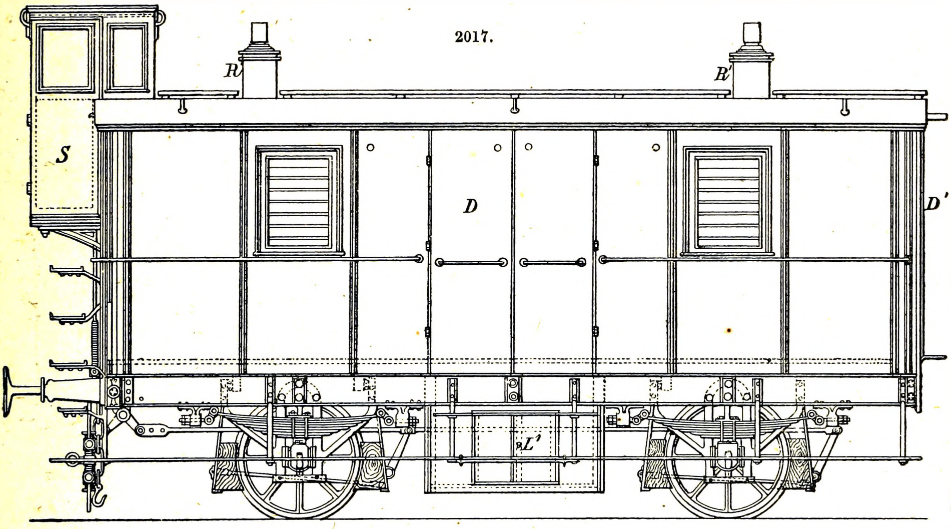

R
V
V
R
V
D
H
P
P
S
D
E
E
L


S
D
B
C
G
E
A
E
E
H
H
H

2016.

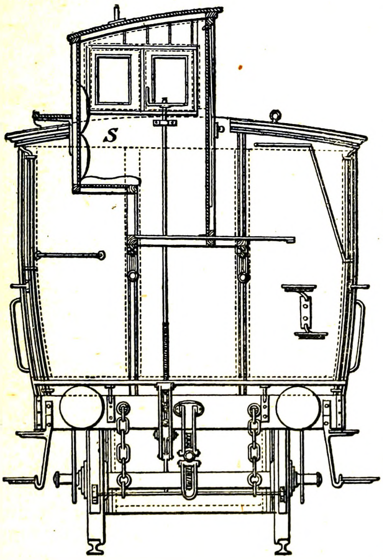
protected from the weather by a flexible passage or casing of waterproof canvas. They are close coupled, being always intended to be run together; and the tender is fitted with a brake worked from a covered guard's seat S, provided at one end. The frames of these vans are of the composite type, with wrought-iron soles and the rest of timber; and the wheels are of wrought iron. Both the vans are of the same dimensions; namely, 21 ft. 9¼ in. long by 8 ft. 9¾ in. wide outside, and 6 ft. 10 in. high inside, at the centre, and are each carried on four wheels, with a wheel base of 11 ft. 4⅞ in. The weight of the sorting carriage is 9 tons and of the tender 8½ tons.

2017.

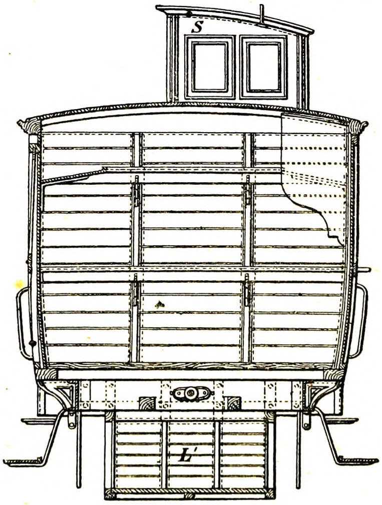


The sorting van, Figs. 2012 to 2016, has no side doors, and can be entered only by the end door D', communicating with the other van. The body is divided by a transverse partition into two unequal compartments, the larger one A constituting the travelling post office, while the smaller B, which adjoins the end door, contains on one side a stove S, and on the other a lavatory and water-closet C. To shut off the latter from the passage, the end door of the vehicle is turned back at right angles to the position it occupies in the plan, Fig. 2016, and is secured by a bolt. The larger compartment of the van A is admirably fitted up, all the furniture and fittings being of polished oak, and of excellent workmanship. Along the sides and across one end extend tables covered with leather, above which are arranged rows of boxes or pigeon-holes P, for the reception of the sorted letters, the interiors of these boxes being covered with green cloth; while underneath each row, brass frames are fixed for receiving the names of the various towns to which the boxes correspond. Two rows of these pigeon-holes are intended for letters containing money or valuables,

2018.

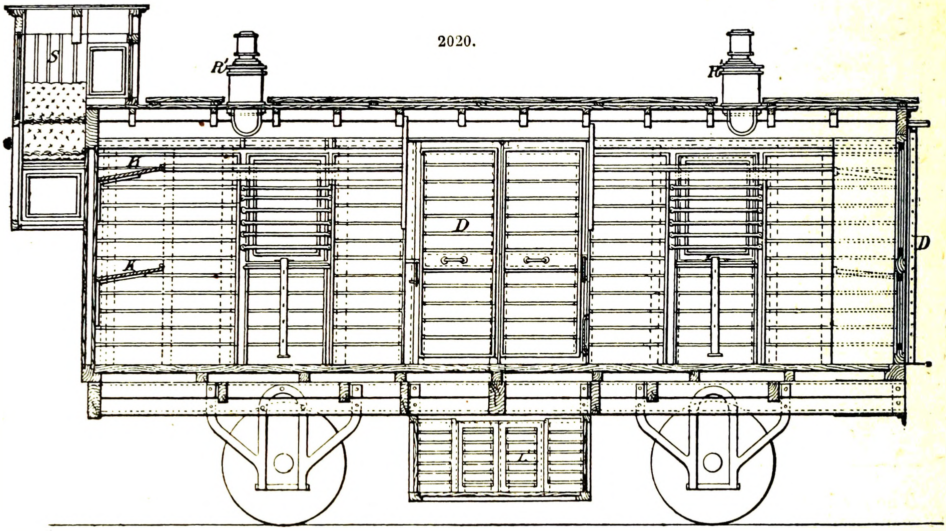


2019.



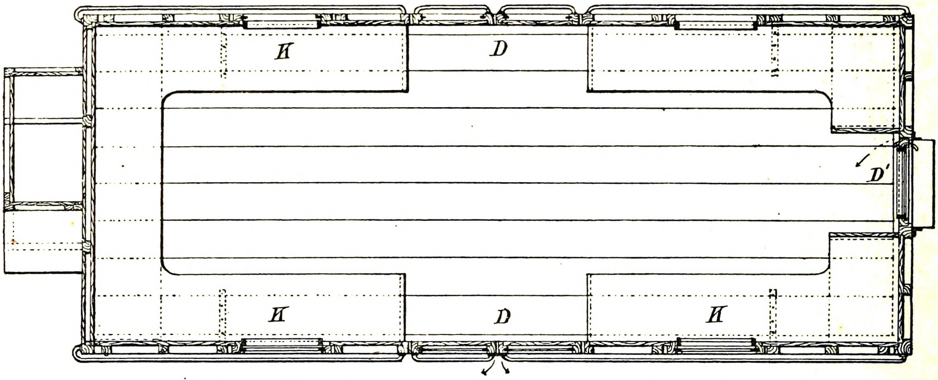
and are fitted with locks and keys. Beneath the tables are drawers and boxes, also fitted with locks and keys, and intended for the reception of parcels, whilst beneath the frame of the carriage, at the centre of its length, is fixed a locker L, with side doors, in which other parcels can be stowed. The office furniture also includes three turning stools E, a chair G, packthread-baskets and knives, hat and coat hooks, luggage carriers, whilst the lighting is effected by two roof lamps R, three movable wall lamps H, provided with pipes V, for leading off the products of combustion, four branches I, carrying candles, and three hand candle-lamps. The warming is effected by a stove S, arranged as shown, there being in connection with the chimney of this stove a contrivance for ventilation on Meissner's system. The ceiling of the carriage is covered with oilcloth, and the floor is of parquetry covered with a carpet of leather.

2020.



The other van, or tender, Figs. 2017 to 2021, has internal fittings of a very simple kind, these consisting merely of shelves K, for the reception of parcels. It is entered by double side doors D, and is provided with the end door D', already referred to. It is lighted by two roof lamps R'. Beneath the floor at the centre of its length there is arranged a locker L', with side doors as in the case of the companion carriage; the side footboards of both carriages being fitted with partitions which fold back to give access to these lockers.

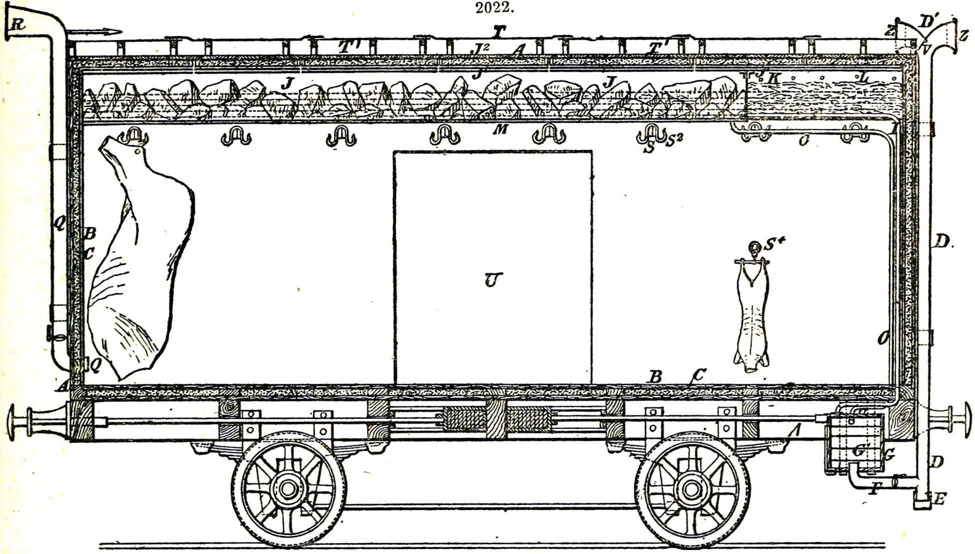
2021.

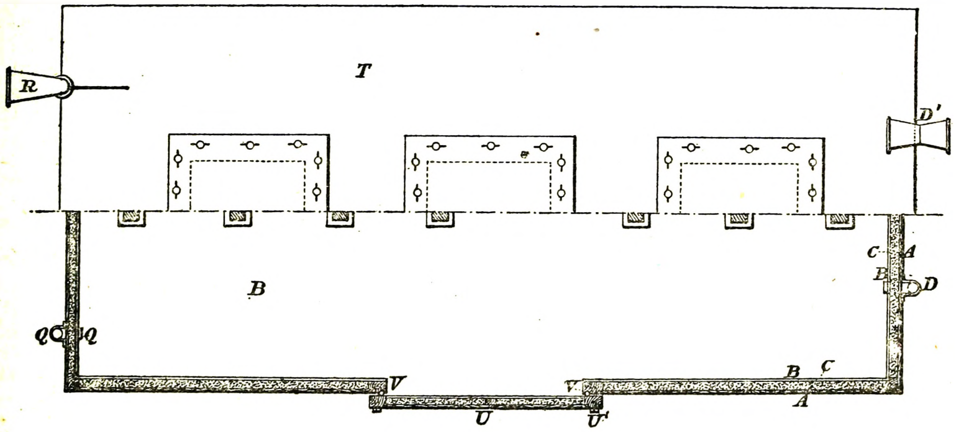


Meat and Provision Waggons.—Waggons intended for the transport of fresh meat, butter, milk, fish, vegetables, fruit, and the like perishable articles in good condition in all seasons and temperatures, must be so constructed that the transmission of heat to the interior shall be practically prevented, the temperature therein being kept as uniform as possible; the said temperature ranging from 31° to 50° F., according to the length of time during which it is required to preserve the provisions. For it must be borne in mind that the temperature to which meat should be exposed during transmission should never be lower than that necessary to secure perfect soundness; as meat which has been stored at a very low temperature, rapidly deteriorates in appearance when exposed for sale in a market, by reason of the condensation of the moisture of the atmosphere which takes place on its surface. Another necessary feature is that the air within the waggon must be constantly changed, and before coming in contact with the articles transported it must be cleaned from the dust, smoke, and cinders with which the atmosphere surrounding a railway train is constantly charged, and it must be cooled and dried. The interior of the waggon also must be so disposed and fitted as to admit the convenient stowage of the meat or other articles to be carried, and must be such that it may be easily kept in a state of perfect cleanliness; the doors being so arranged that while affording perfect facility for entering the waggon and loading and unloading, they can be hermetically closed, absolutely excluding the passage of air.

One of the best of these railway provision waggons, or refrigerator cars, as they are often termed, is that of W. D'Alton Mann, of Mobile, Alabama, U.S, Figs. 2022 to 2024; Fig. 2022 is a longitudinal section of the waggon, Fig. 2023 is a cross section, and Fig. 2024 a plan partly in section. The walls, roof, and floor of this waggon are double; the outer casing A being formed of planks or boards, and the inner casing B of sheets of zinc or other metal not subject to oxidation; the floor has also planking under the zinc. To one or other of these casings, on the inner surface, there is added a sheathing C of pressed paper board, or similar material, and the space between the two walls A B is filled with sawdust, charcoal, or other slow heat-conducting material. For the introduction of fresh air into the waggon with the necessary force when the waggon is in motion, one or more pipes D are provided, each terminating in a double funnel D′ at the top of the waggon, and in the throat of these double funnels is placed a valve V; the movement of the waggon in either direction causing the entrance of air by one mouth of these funnels, and the valve V automatically closing the throat of the other funnel. The air in entering the funnels D′ encounters first a sheet of wire gauze Z, which intercepts the larger particles of dirt, sparks, and the like; the air thus partially cleansed then descends the tubes D, and is further purified by the precipitation of other particles of dust into the cups E at the bottom of the tubes D, the dust cups, for facility of emptying, being attached to the tubes D by bayonet fastenings. The air then passes by the branch tubes F′ into the large box G, which is suspended from the waggon frame, and is filled with damp willow shavings, hay, grass, or other suitable material; and in order that these willow shavings, or other material, may not settle into a dense mass, a number of horizontal wires or thin spikes G′ are attached to the back of the box G, projecting nearly to the

2022.

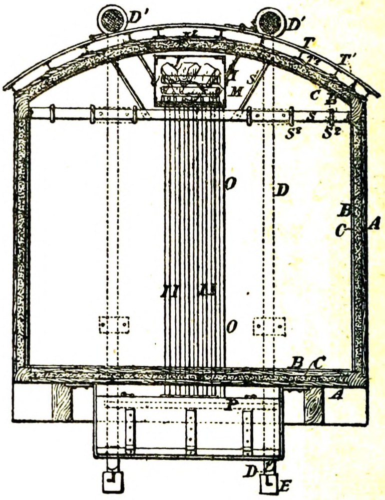




2023.

front, and with the shavings, or other material, distributed among them; the front of the box G has a door H, hinged near the bottom, which is water-tight; therefore a certain quantity of water is retained in the bottom of the box, the surplus quantity dripping out at this door; and the air passing through this mass of damp shavings, or the like, is freed from the dust and cinders that may not have been previously removed from it. The air then ascends, and passes through the vertical tubes I, and through the horizontal portions I′ of the same, through an ice tank or reservoir J, placed at the top of and entirely within the waggon; the said tubes I being so bent and arranged that they pass and return through the entire length of the ice reservoir, constantly ascending, or inclined upward, in order that the water condensed from the air passing over the inner surfaces of the pipes resting in the ice, may drip back into the box G. This arrangement is most important for ensuring a dry condition of the air entering the waggon, which condition is essential for the proper preservation of meat and similarly perishable articles. The air is thence discharged at different points into the compartment K, which is loosely filled with blocks of charcoal, or other material that will rapidly absorb moisture. From this compartment K the air escapes at the top on either side the openings L, and passes over, and is then disseminated throughout the waggon in a purified, cooled, and dried condition. The ice reservoir J is formed of galvanized iron or other non-corroding metal, and may advantageously be corrugated; it is placed wholly within the body of the waggon, and thus presents the area of its entire surface to the air in the waggon, and therefore acts most efficiently to cool the same. At the bottom of the reservoir J is provided a gutter M, into which any moisture on the outside of the ice reservoir will drip, such drippings being conveyed therefrom through a pipe, into a receptacle provided for it at the bottom of the waggon. The water resulting from the gradual melting of the ice in the reservoir J is conducted by a small tube O into the box G, where by means of a perforated tube P it is so distributed as to moisten and cool the entire mass of material in the box. The air forced into the waggon through the funnels D′, as above described, is exhausted at the opposite end of the waggon by means of the vertical tubes Q. These tubes are placed outside the waggon, with their lower end extending and opening into the same, and they are each provided at the top of the waggon with a funnel or exhauster R, so jointed thereto as to turn freely with any change in the direction of movement of the waggon; and thus throughout the movement of the said waggon a strong draught from the interior outwards is produced by these funnels, which draught acting in combination with the forcing action of the fixed funnels D′ at the other end of the waggon, whenever the latter is in motion, will ensure a rapid change of the air in its interior; the rapidity of this change of air being regulated by valves in the inlet and outlet pipes. To carry the hooks for attaching the carcases of meat, the beams S, which consist of flat bars of iron arranged in pairs, are placed across the waggon at the cornice, the said beams being stayed to the roof by the diagonal braces S^1, and on the beams S are placed a number of suitable hooks for the suspension of the entire carcases or large joints of meat. A second series of movable beams S^2, fitted with hooks, may be inserted at a proper height to support smaller joints or pieces of meat; or long movable hooks may be temporarily attached to the beam S to serve this latter purpose. When the waggon is required for carrying fruit, vegetables, flowers, and the like, it is provided with racks or shelves in place of the beams and hooks above described. The ice tank J is suspended from the rafters by strong straps, thus leaving the entire length of beams clear for the adjustment of the meat hooks, as shown in the cross section, Fig. 2023. The ice reservoir J and the compartment K are fitted with doors J′ in the top to admit the ice and drying material, the said doors being accessible by corresponding doors or traps in the double roof, so constructed as to be air-tight when closed. To effectually ensure the protection of the waggon roof from the direct rays of the sun, a false roof T formed of canvas stretched over light rafters T′, which are supported by brackets, is placed a few inches above the true roof R, this false roof being also provided with doors or traps to permit access to the doors J″ in the true roof. The doors U slide on rollers, and to ensure the air-tight closing of these doors, an indiarubber tube V′ is placed entirely round the opening in the waggon sides, and the door, when shut, is brought firmly against this indiarubber tube by means of the bolts U′, which pass through the door and screw into tapped holes of the wall of the waggon, thus ensuring a perfectly air-tight joint between the sides of the waggon and the door. The door U is sometimes formed double, or in two parallel parts, one fitted inside and the other outside of the waggon walls. To facilitate the proper cleaning of the interior of the waggon, the interior surface of the floor is made to slightly incline to the centre throughout its entire length, and a hole or well in the floor, fitted with a suitable plug, permits the escape of fluids dripping from the meats or used in cleaning the waggon.

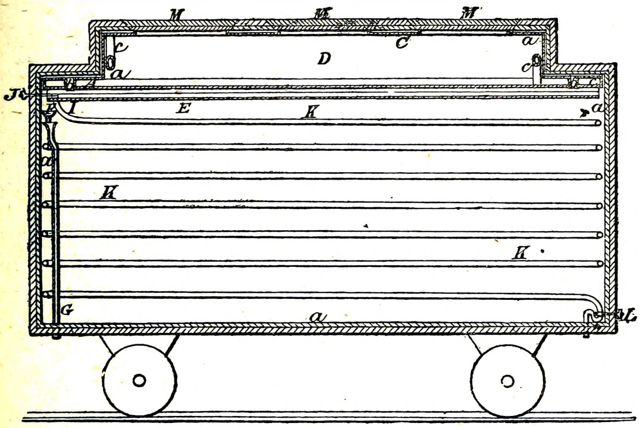
2024.



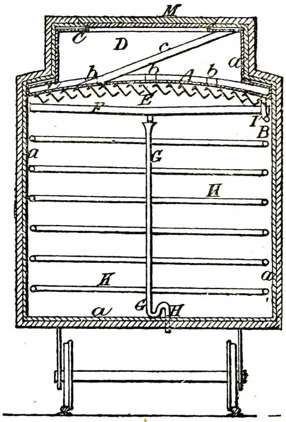
Figs. 2025, 2026 are of Knott's refrigerator car, or provision waggon, Fig. 2025 being a longitudinal section of the waggon, and Fig. 2026 a cross section of the same. The whole of the interior of this waggon is surrounded or lined with any suitable non-conducting substance *a*, and is rendered perfectly air-tight. The chamber or receiver A D for containing the required refrigerating agents for producing the desired low temperature, is formed in the top of the waggon. This chamber or receiver is constructed of any suitable metal, and is made of the same width as the interior of the waggon, and is supported on suitable ledges B, fixed along the sides of the waggon.

A small space C is left between the top and the ends of the receiver A D and the non-conducting lining *a* of the waggon for the passage of air. The top part D of the receiver A D is made somewhat shorter and narrower, but deeper, than the lower part A, as shown, and serves for the introduction of the refrigerating agents from the top of the car, which is provided with air-tight closing doors M for that purpose; *b* are pipes or tubes passing through the shallow part of the receiver or tank A, for the downward passage of the cold air, as hereinafter described; *c* similar pipes passing in an oblique direction from top to bottom of the receiver or tank A D. On the under side of the said receiver are fixed a series of gutters E, so arranged as to collect the condensed moisture and to carry it to a transverse gutter F, placed at the end of the carriage, the condensed moisture being carried off from the said gutter F, and discharged outside the carriage by the pipe G, which is provided with a siphon H at its lower end, to prevent the inlet of the external air. From the bottom of the receiver A passes a pipe I, communicating with the coil of pipes K passing round the inside of the waggon as shown, the lower end of the said coil passing out through the bottom of the waggon, this pipe being provided with stop-cocks J and L. In this waggon the carcases or joints of meat or other perishable articles to be preserved and transported, or stored, are hung or packed in any suitable manner, and the refrigerating agents are introduced into the receiver A D through the doors M in sufficient quantities to produce the degree of temperature required, and the doors are then closed air-tight. The air in the waggon will then, in a short time, be brought to an even temperature in the following manner:—The warmer portion of the air will pass up through the spaces C to the top of the receiver A D, and will become cool and descend through the tubes *b* and *c*, and any moisture which it may contain will be condensed in these tubes and on the outside surface of the tank, and be collected in the gutters E, the construction of the said gutters at the same time allowing the cold air to pass downwards, as shown by the arrows, and the moisture which is collected in the said gutters will run into the transverse gutter F, whence it will be discharged through the waste-pipe G outside the carriage. When the refrigerating agents in the receiver A D shall have become partially exhausted, the stop-cock J is turned on, and the partially exhausted agents will pass into the coil K, and when thoroughly exhausted they are discharged through the stop-cock L. In the meantime, the stop-cock J having been turned off, the receiver A has been filled with a fresh supply of refrigerating agents. By this arrangement the power of the refrigerating agents, consisting of ice and salt, is fully utilized.

2025.



2026.



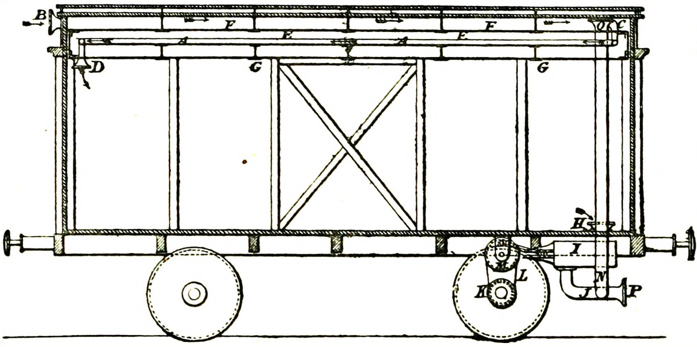
From the above description it is evident that in this waggon there will be a continuous circulation of the contained air, which will be constantly kept in a dry state, for any moisture therein, or which may form therein from its contact with the meat or other articles in the waggon, will be condensed, and then be collected in the gutters E and F, and be discharged outside the waggon.

It will thus be seen that this waggon differs considerably from that of Mann, through which a continuous current of fresh air is maintained, while in Knott's waggon the air remains unchanged from the time of loading until the waggon is opened for the removal of the meat or other provisions.

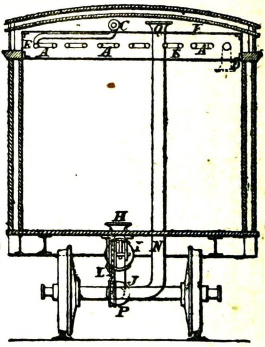
Tallerman, Gruning, and Dawnay's refrigerating waggon, Figs. 2027 to 2029, combines the advantages of the two systems above described, as by the opening or closing of certain valves, either the same air may be continually circulated through the waggon, as in Knott's system, or a continuous current of fresh air may be passed through the interior, as in Mann's waggon.

The body of this waggon is constructed with an inner and outer boarding, having either a non-conducting lining between or a clear air space, but the invention may also be applied to any ordinary covered waggon without double boarding. Fig. 2027 is a longitudinal vertical section of the waggon; Fig. 2029 is a half plan of coil, and half plan of ice-tank doors; and Fig. 2028 a vertical cross section of the waggon. The pipes A are arranged as a coil for the circulation of the air through the cooling medium; B is the inlet pipe from the outer air; C is the inlet to the coil; D the exit trumpet-mouth into the interior of the waggon; E is the ice or freezing mixture tank, of wrought iron; F are the iron covers of the same, opening upwards; G are iron bearers supporting the coil of pipes A, and also forming the substructure of the tank E; H is the pipe leading to the exhauster; I the exhauster; J the exit of the same, or discharge pipe; K is a pulley keyed to one of the axles of the waggon; and M a pulley which is keyed to a cranked axle carried by brackets, pendant from the bottom of the waggon, motion being transmitted from the pulley K to the pulley M by the strap L, the said pulleys and strap driving the exhauster I. N is the circulating pipe to be used when it is required to circulate the same air continuously through the waggon; and O are movable wooden covers forming the outside roof of the waggon, the said covers being made in sections to admit of easy removal, and fastened down by catch hooks and studs.

2027.

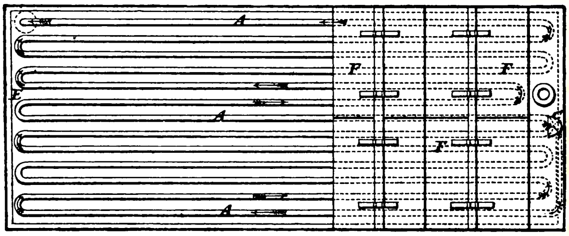


2028.



The method of working is as follows:—The tank E being filled with ice or other freezing mixture, and the van being sent forward on its journey, the motion of the wheel axle communicates motion to the parts K, L, M, which work the piston of the exhauster, and the air is drawn in at the inlet B, and passes over the top of the tank, becoming partially cooled in its passage. It is then drawn through the coil A, out at the exit D into the van, and thence into the inlet H, and is passed by the exhauster out into the atmosphere. To effect a continuous circulation of the same air, each of the trumpet mouths B, D, Q, P is provided with a circular cover, which may be opened or closed at pleasure. On closing B and P it will be evident that all connection with the outer air will be prevented, and that thus the air contained in the waggon will be drawn into the exhauster I, and continuously circulated through the cooling apparatus.

2029.



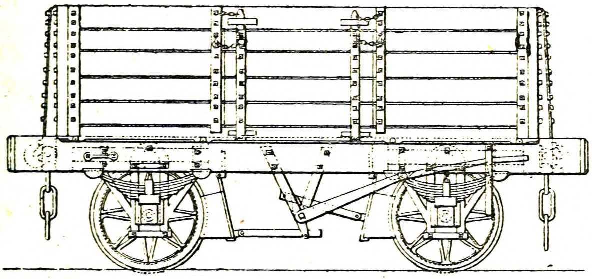
Goods Waggons.—We come now to the consideration of Goods and Mineral Waggons; for the following remarks on which we are indebted to a paper read before the Institution of Civil Engineers, by W. R. Browne.

"The designing of a railway waggon has its peculiar difficulties, arising from the fact that, in addition to the ordinary strains, which can be calculated and allowed for, such a waggon is also subject to sudden and extraordinary strains which defy calculation; and it is these strains which have chiefly to be considered in the building of a waggon. The leading principle, therefore, must be that all parts should be strong enough to sustain, without injury, the greatest shocks to which they are liable in ordinary working; from which it follows that the strength of a railway vehicle must not, as in other structures, be proportioned to the load it has to carry. To show this by an example, take the ordinary sole-bar of an 8-ton or a 10-ton waggon. This, following the dimensions specified by most railway companies, will be a piece of American oak, 12 in. deep by 5 in. wide, and carrying a distributed load over a length of about 14 ft. Taking 10 tons as the load, and 4 tons as the weight of the waggon itself, exclusive of wheels, axles, and springs, this distributed load will be 7 tons, or just $\frac{1}{2}$ ton a ft.; and this load is supported on the two axles, which may be taken at 8 ft. apart. On calculating the bending moments at the centre of this wheel base and over the axles respectively, it will be found that the latter is the greatest, and that its value in inch-tons is $\frac{3}{2} \times 18$ or 27. But calculating the breaking strain of a 12-in. by 5-in. section in the ordinary way, and assuming $\frac{4}{7}$ as the modulus for inch-tons, the moment of rupture is found to be 564. This gives a factor of safety of 21, or at least double what would be required in an ordinary timber structure. It follows that some other consideration must have led to the fixing of this scantling; and this of course lies in the fact that the sole-bar has not merely to carry the load, but to carry it under all the varying circumstances of shock and strain which have already been alluded to. It might seem an obvious deduction from the foregoing that the load of waggons, meaning thereby the total weight carried, in opposition to the "tare" or dead weight, ought to be largely increased. If the underframe of a waggon must in any case be made so strong that it would carry 20 tons as easily as 10 tons, would it not be true policy to put something approaching to 20 tons upon it? This leads at once to the question, which ought obviously to form the first stage of inquiry, namely, What is the proper load for an ordinary waggon? The leading principle would seem to be, that the load should be as great as possible, but for reasons which will be pointed out, the question may be said practically to lie between 8 and 10-ton waggons. The question being thus narrowed, the difference between the cost and weight of an 8-ton and a 10-ton waggon has to be considered.

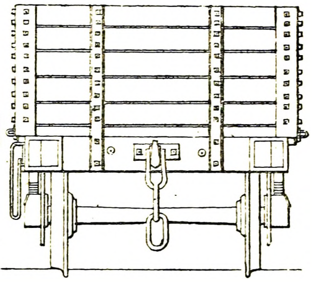
"Figs. 2030 to 2033 relate to an ordinary 8-ton coal waggon, as built by the Bridgewater Engineering Company, the tare of which is about 4 tons 7 cwt. A similar waggon constructed to carry 10 tons would weigh about 4 tons 14 cwt. This comparison would appear to prove that the 10-ton waggon was decidedly the proper type, and that, as even here the factor of safety is far too high, a yet greater load might be resorted to. This conclusion, however, is negatived by the two following considerations;—

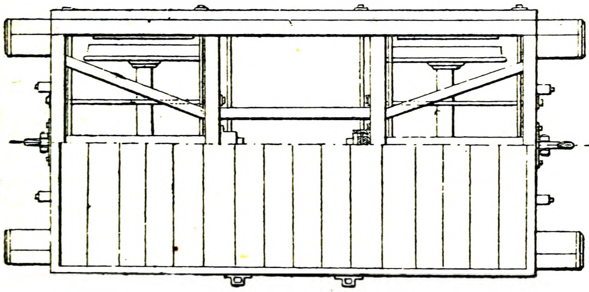
"Waggons not only have to be hauled by locomotives; they have also to be shifted by horse-power in yards and sidings; obviously therefore, it is a fatal objection if a waggon is too heavy for a single horse to move it. Now it requires all the strength of a powerful horse to start a 10-ton waggon, fully loaded and in ordinary working order, upon a dead level; to start it on anything like an incline is too much for him: hence 10 tons is the extreme limit admissible for the load.

2030.

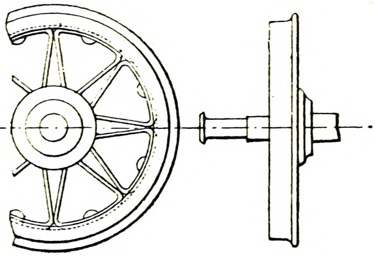


2031.





2032.



2033.

"It is comparatively seldom that a waggon is loaded up to its full capacity. This arises from several causes. Thus in the first place, the contents of a waggon are often too bulky to make up the full weight; secondly, the whole quantity of goods to be sent is often less than this weight; a truck comes into some private yard and is loaded, say, with 3 tons of castings, which are quite sufficient to constitute what is called a 'truck-load'; it is returned to the station, and thence goes direct to its destination, no weight being added, because nothing else offered having the same consignment; while, thirdly, the goods traffic on a railway is seldom equal in the two directions; hence waggons have constantly to be sent back empty. There are, unfortunately, no statistics with respect to English railways which will enable a judgment to be formed of the effect of these causes, and so to approximate to the average load of a waggon. For the railways of France, however, such statistics do exist, though not in a perfect form. From an analysis of these reports for the six great railway systems of France by Ernest Marché, it has been found that, roughly speaking, one waggon in five is running empty and the other four are loaded to rather less than half their carrying capacity. It is possible that English lines, on account of their much larger mineral traffic, would show more favourable results; but the difference probably would not be great. Looking at these facts, and remembering that the extra weight and cost of a 10-ton waggon are entirely wasted whenever its load does not exceed 8 tons, it would seem that the latter is probably the best figure to take for purposes of general traffic. An exception may arise in the case of coal or ore waggons owned by private firms and used only for a single purpose. These are commonly loaded at the pits to their full weight, and in such cases the shunting is so generally done by engine instead of by horse-power that the other evil is not so important. Taking, however, an ordinary goods waggon, such as railway companies use for general purposes, the case may be summed up by saying, that even if built for 10 tons it will rarely have more than 8 tons to carry, and that when it has, its cumbrous weight will be likely to cause trouble both at the beginning and at the end of its journey.

"Another question which arises in designing goods waggons is, whether it is wise to provide, as far as possible, special types of waggons for the various classes of traffic. This proposal has often been made, and it is certainly plausible at first sight. As has been pointed out, a heavy waggon may receive, say at High Wycombe, a consignment of cane-bottoned chairs, to be delivered at Bristol; and though built for 10 tons, will be thus travelling with a load amounting only to a few hundred weight. Or again, the Great Western Railway forwards daily throughout the spring many trucks full of cauliflowers, grown in Cornwall, but destined for the London market. In these and all similar cases there is no doubt that special types of light waggons might be designed which would offer great advantages for the conveyance of these particular loads. But this course is open to two fatal objections.

"Supposing the light waggon to have deposited its freight of chairs at Bristol. It has then to be sent back, and it is of course desirable that it should not go empty. But the goods going from Bristol towards London are not of a light character, and perhaps the only consignment offering is a ponderous casting, or some heavy barrels of sugar. There is then only the choice between sending the waggon back light, or loading it beyond its proper capacity.

"Whether loaded or not, the light waggon will have to travel as one of a long train of waggons, most or perhaps all of which are of a much heavier and stronger build than itself. In cases of accident, or in the ordinary events of shunting, starting, and stopping, the light waggon will be much in the position of the earthenware pot in the fable; it will meet with so much rough usage, will be so mauled and hammered by its neighbours, that its life, under the most favourable circumstances, will be of short duration.

"These two considerations seem fully to justify the course which has been taken by railway companies, both here and on the Continent, in reducing as far as possible the number of classes of waggons. There must always, however, remain a considerable number of varieties to provide for traffic to which ordinary waggons are unsuitable. The chief of these are covered for perishable goods, cattle, timber, coal and mineral, coke, platform for heavy masses, such as boilers, refrigerator cars for the conveyance of fresh meat, fish, fruit, and the like, and some few other classes. But much may be done to economize even these; thus, cattle waggons may be used for coke, or at another time for light bulky articles, such as would generally be carried in covered waggons; boilers may be conveyed on timber waggons, and so forth.

"Having then decided the most economical capacity for a goods waggon to be 8 tons, and that it should never exceed 10 tons, while its form should be such as to render it as generally useful as possible; the next consideration is its design in detail; and for this purpose a waggon may be divided into the following parts, beginning from below;—

"Wheels and axles. Axle boxes. Springs. Underframe, axle guards, and connections. Draw gear. Buffers. Body.

"Fig. 2031 is the type of wheels and axles commonly employed for ordinary freighter's waggons in England. The wheels consist of a cast-iron nave or boss, with wrought-iron spokes cast into it, and bent round to form a skeleton on which a steel or weldless iron tire is shrunk and secured by rivets. The diameter of the axle is 5 in. in the wheel seat, and 5⅛ in. just inside the wheel, thus forming a shoulder; thence it tapers to 4¼ in. in the centre; while outside the wheel it is reduced to 3½ in. for the journal, which is 7 in. long; and these dimensions do not vary much from those in use on the chief systems both at home and abroad.

"The great diminution in size, both at the journal and in the centre, is, at first sight, hard to account for. The axle may of course be considered as a beam, loaded at each end, in the journals, by the half weight of the truck, and kept in equilibrium by the two upward pressures of the rails, passing through the wheels. It is thus under the action of two equal and opposite couples, in which the force is half the weight of the truck, and the arm is the distance between the centre of the journal and the centre of the boss. As the effect of such a couple is precisely the same at every point of the axle, it would seem that the diameter should also be the same everywhere. But it must be obvious that an axle is never endangered by the regular statical load brought upon it; its fracture being always occasioned by some sudden shock, such as might be caused by a stone placed on one of the rails, when the whole axle will act, for the moment, as a beam fixed at one end and receiving a blow at the other. This will of course produce its greatest effect at the fixed end, that is, in this case, close to the disturbed wheel; from thence the effect will diminish to its lowest value at the other, or undisturbed wheel. This is the reason of the reduced diameter at the centre, the strain there being always less than at one or other of the wheels. The diminution is of course proportional to the moment of resistance, and therefore to the moment of inertia of the section; as this in a circle varies as the fourth power of the radius, the ratio of the diameter at the centre to that at the wheel seat should equal $\sqrt[4]{\frac{1}{2}}$, or 0·84, a proportion very near to that found in practice. The utility of this diminution has been questioned; but the above reasoning seems fully to demonstrate its theoretical soundness, while practically it effects a considerable saving in weight and cost. The same reasoning accounts for the well-known fact, that axles generally break just inside the wheel seat. This point is, in fact, that at which the cantilever is fixed, considering the axle as such, and therefore that at which the intensity of strain is greatest. It is obviously desirable to avoid anything which may tend to weaken the section at this point. On some railways it is the practice to have a shoulder about ⅛ in. deep on the axle, just inside the wheel, to prevent the latter from working inwards, but the great tightness with which wheels are now fastened to their axles, seems to render this unnecessary, and, in fact, on many lines it is dispensed with altogether; in any case, the difference between the first and the finishing cut of the lathe used in turning down the axle would seem to be amply sufficient. Anything more than this is objectionable, from the well-known fact that an abrupt change of section, in any piece subjected to impulsive strains, has a marked tendency to produce fracture.

"The greatly diminished size which may be given to the journal is also mainly due to the fact above noticed, namely, that it is a blow delivered by one rail which produces the most violent strain on an axle; another cause, however, which no doubt comes in to assist the journal, is the operation of the bearing spring, through which the weight is transmitted. When a wheel passes over an inequality, the weight of the truck must of course come heavily down upon the journal;

but the effect is taken off by the yielding of the bearing spring, and changed from a violent blow into a gradual pressure. This leads to the inquiry whether the shock to the wheel seat might not be, to some extent, 'cushioned' in a similar manner. This clearly implies the giving of a certain amount of elasticity to the wheel itself; and this has apparently been accomplished in the wooden wheel system, now so frequently used, especially for carriages. The space between the boss and the tire is here filled up by a series of hard wood blocks, set endwise to the fibres, and secured both at the boss and the tire by rings of plate iron. This system has been in use on the London and South-Western Railway for thirty years. The wood used in the first wheels was teak, which was saturated with oil and white-lead by a process similar to creosoting, that is, by placing the blocks in a receiver, first exhausting the air to remove the sap, and then forcing in the oil and lead under a pressure of 90 lb. to the sq. in. Some of these wheels have lately been taken off and cut down to a smaller diameter; the wood being found to be perfectly sound. The breaking of an axle has never been known to take place with these wooden wheels, a result which can only be due to the elasticity they possess. These wheels are lighter than ordinary iron wheels, the total difference being as much as 3 cwt. per pair; and their first cost is not much greater. The tires rest directly on the wood, so that no skeleton is required, and are secured by some kind of clip fastening and not by rivets.

"In the sharpest possible contrast to these elastic wooden wheels, is the chilled cast-iron wheel so much in vogue in America. The merits of this wheel have often been discussed; and its excessive rigidity would certainly seem to form a great objection to it; though this would appear not to have been felt in the States, where the permanent way is often of the roughest description. Possibly the curve which is usually given to the section between the boss and tire, in order to allow for contraction, may give to the wheel, when in use, a certain degree of elasticity.

"Before leaving the subject of wheels and axles, it should be noted that one important point to be aimed at is the prevention of the wear of the journals. The skeleton and boss of a wheel, and the whole length of the axle, are practically subject to no wear and tear whatever; and though tires wear out, they can easily be renewed. Thus the life of a pair of wheels would be indefinite were it not that the journals wear down, and the wheels are then useless. An obvious remedy is to 'bush' them with brass or white metal; but as obvious an objection is, that the arm at which the bearing friction acts would thereby be increased. Another device would be to make the journals in separate pieces and screw them into the ends of the axles; but there might then be fear of their working loose. This point is one which would seem worthy of attention.

"The next part of the waggon to be considered is the axle boxes, involving the important question, whether oil or grease should be preferred as a lubricant. At present oil is universal in hot climates, is general in Germany and in the United States, and is largely used in England by railway companies; but grease is almost the only lubricant used for private waggons. The advantages of the latter are its cheapness and facility of application. The real ground of its use is probably the much greater cost of an oil axle-box. The advantages claimed for the oil axle-box would seem to outweigh this difference in prime cost. These are;—The quantity of the lubricant used is so much smaller that it needs to be renewed very seldom. Should the supply run short, the box heats, not suddenly, like a grease box, but gradually, taking two or three days to arrive at a dangerous temperature; this of course increases the chance of its being discovered in time. There seems to be no doubt that the friction resistance is decidedly smaller with oil than with grease, a point of vital importance. The general result of a series of experiments on the London and South-Western Railway was, that with oil the resistance to traction of a waggon in motion was only 3 lb. a ton, whilst with grease it was about 9 lb.; on the other hand, the resistance of a waggon at rest to being started was somewhat greater with oil than with grease, but the difference was not large, 15 lb. and 13 lb. a ton respectively.

"With regard to axle guards, the W-shape, now universal, probably admits of no improvement. The thickness of the iron, $\frac{3}{4}$ in., is also fixed by general consent. The width, however, is generally excessive; on many railways $3\frac{1}{2}$ in. being still the minimum. It is believed that, where the iron is, as it ought to be, first-rate, a width of $2\frac{1}{2}$ in. is ample, even for the crowns, and that for the wings $2\frac{1}{4}$ in. is sufficient. It must be remembered that both the pulling and the buffing strains are transmitted through the body of the waggon; consequently the stress thrown on the guards by sudden stopping or starting is only that due to the momentum of the wheels and axle, weighing together about 14 cwt. This can never be very great; and, even with the moderate width used by some railways, the fracture of an axle guard is almost unknown.

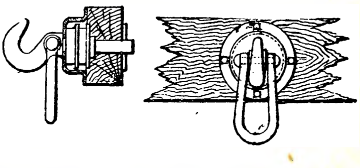
"The spring adopted by the Highland Railway Company is flat and long, like a carriage spring, consisting of nine plates $3\frac{1}{2}$ in. by $\frac{1}{2}$ in.; the uppermost 3 ft. 6 in. in length. On other lines the plates have a decided camber; their width varying from 4 in. on the Caledonian to 3 in. on the Great Western, and whilst in the former case they are ten in number, each $\frac{1}{2}$ in. thick, in the latter there are two plates $\frac{3}{8}$ in., and fourteen plates $\frac{5}{16}$ in. A much lighter spring is that used on the Cambrian railway, which consists of ten plates 3 in. by $\frac{3}{8}$ in., and one plate 3 in. by $\frac{1}{2}$ in. Probably a simpler form even than this would suffice. In a waggon great flexibility is not necessary; and strength is best consulted by making the plates few and thick; since in a laminated body the several parts act almost independently, and the sum of their strength gives the real strength of the whole. Hence, as the strength of a beam varies as the square of its depth, six plates $\frac{1}{2}$ in. thick will more than equal ten plates of $\frac{3}{8}$ in. thick; and it would seem that a spring consisting of only seven plates 3 in. by $\frac{1}{2}$ in. would have sufficient strength, and probably also sufficient elasticity. Such springs would not weigh above 2 cwt. 2 qrs. a set, in comparison with 4 cwt. 2 qrs. 20 lb., the weight of the Great Western springs.

"In Fig. 2032 is shown the plan of an ordinary oak underframe for an 8-ton waggon. The diagonals should always incline from the centre towards the buffers, and not, as sometimes seen, from the ends of the middle bearers towards the draw-bar. In the latter case they give no assistance against the pull of the draw-gear, because they cannot act as ties; in the former they are able to assume their proper function as struts, and thus help to support the 'buffing' strains. This difficulty as to ties constitutes, in fact, the chief disadvantage in wooden structures. In an underframe it compels the use of wrought-iron tie-rods both along and across the frame. Looking at this, an underframe of combined wood and iron would seem desirable, in which angle or T irons should act both as supports and ties; but such combinations are rarely successful. Carrying the same idea still farther, many engineers have built underframes wholly of iron, but the advantage of this is more than doubtful. For on comparing the properties of American oak and wrought iron, as given in Rankine's 'Rules and Tables,' it will be found that the following is approximately true;—a bar of iron in comparison with an exactly similar bar of oak has five times the strength to resist tearing, six times the strength to resist crushing, and four times the strength to resist cross-breaking; but, on the other hand, it has ten times the weight and twelve times the value. Hence to have, say, a sole-bar in iron of the same strength as one in oak, one-sixth the scantling must be given; but in that case it would weigh 66 per cent., and cost 100 per cent. more than its rival. This result is completely borne out in practice. The weight of the oak underframe shown is about 12 cwt., including tie-rods. But an iron underframe of the same general character and size, if made with the usual dimensions, would weigh about 16 cwt. Against this there seems only one point to urge in favour of iron, and that is its great durability. But this may easily be bought too dear. In the first place, waggons get out of date. But apart from this, the ordinary life of a waggon is so hazardous, exposed to so many natural and unnatural shocks, that its average duration is much below what would be due to the ordinary processes of decay. On this point, as might be expected, opinions differ much, and statistics are hard to obtain. The engineer of one important railway states that the number of waggons destroyed by accident is so small as not to be worth consideration. The engineer of another line, equally important, says, that on an average waggons will not run above twelve years before coming to a violent end. Probably the truth lies between the two. At any rate, there seems good reason to conclude that durability is by no means the most important point in designing such a structure as a railway waggon; and, in fact, so fully has this been realized by some leading authorities, that on the vast system of the Midland Railway, for example, iron underframes are completely unknown.

"Another point remains for consideration, namely, the scantling to be given to the headstocks, sole-bars, and middle-bearers. In the waggon shown these are all 12 in. by 5 in., and this is the scantling fixed by most of the leading railway companies for private waggons; but at the same time dimensions much below these are known. These dimensions may be necessary for the sole-bars and headstocks, as it is these which have to bear the chief strains, but for the middle-bearers they would seem excessive. The reason for strengthening these is, no doubt, the fact that with ordinary draw-gear, the whole strain of traction is brought upon them; but with continuous draw-gear this is not the case, and then these middle-bearers, especially if the bottom planks run across, not along the frame, have but little to do. In any case, the model waggon may be assumed to have sole-bars and headstocks of 11 in. by 4$\frac{1}{2}$ in. scantling, and middle-bearers and diagonals of 11 in. by 3 in.

"The draw-gear, Fig. 2034, employed for waggons consists of a hook at each end of the truck, with a shackle and chain attached to it. This hook is welded on to the end of a bar, 1$\frac{3}{4}$ in. round in general, which passes through the headstock and generally also through the middle-bearer, and is made to bear against the latter by means of a nut and indiarubber washers. An improvement on this is the continuous draw-gear, which consists in uniting together the inner ends of the two draw-bars, so that they form one system, and the traction is obtained by the draw-hook in rear of the truck bearing against its headstock. It is clear that in the first case the body of the truck forms itself a link in the chain of traction, and the whole resistance of the hinder part of the train is transmitted through it as a tensile strain. In the continuous system, on the other hand, the draw-bars form the chain, independently of the waggons, and the whole strain on any one of the latter is that due to its own resistance to traction conveyed in the form of pressure which it is best adapted to resist. The disadvantage of the continuous system is its great weight and expense. The heavy draw-bars, extending the whole length of the truck, do not add to its strength in the slightest degree, and the cradle, or intermediate piece which connects the draw-bars together is always cumbersome and costly. In view of this, a system of continuous draw-gear, Fig. 2034, has been designed. The indiarubbers are there contained in a wrought-iron case fixed upon the outside of the headstock; and the strain is transmitted through four $\frac{7}{8}$-in. rods, which at the same time act as the longitudinal ties of the underframe. The draw-hook terminates in a short shank, which passes through the headstock to get an inside bearing. The advantages aimed at are;—A saving in weight and cost, since the ordinary tie-rods are dispensed with. The avoidance of a weld in the draw-bar, hence the risk which always attends a welded piece is absent. The indiarubbers are outside the truck, and more easily accessible when required. The strain is transmitted through four rods instead of one; and should one of these happen to be of inferior quality and give way, the other three would probably hold, at any rate till the waggon reached some place where the failure would be observed.

2034.

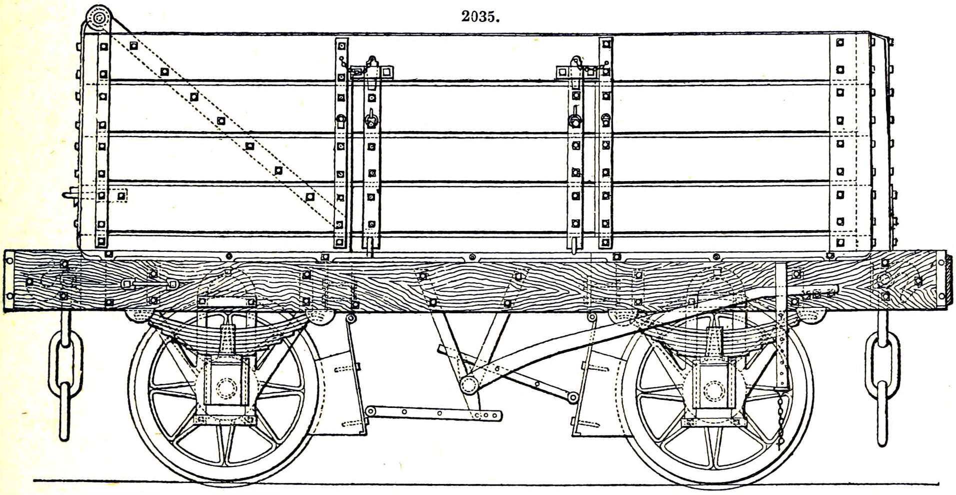


"Before leaving the subject of draw-bars, a word may be said upon safety chains. These, which were once in general use, have been mostly abandoned, for it has been found that if a draw-bar breaks, the safety chains also inevitably break under the shock brought on them by the separating train. This, in fact, has so often been the case that their discontinuance is not to be wondered at; indeed, in more than one instance they have done actual harm by one of them holding while the other gave way, and thus getting the waggon across the line.

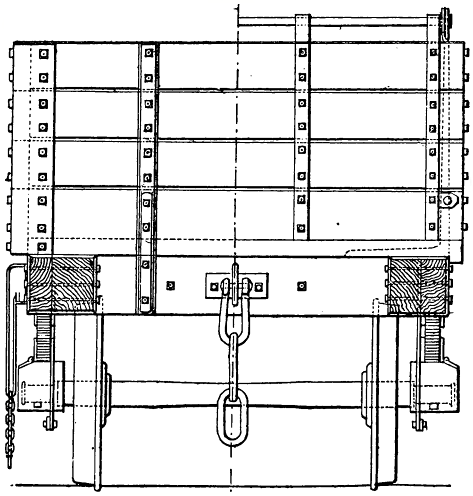
"There would seem to be a growing inclination to abandon spring buffers, at least in mineral waggons; and this tendency, once begun, is likely to increase, since a waggon with spring-buffers placed in a train of others having 'dead' buffers only, is sure to fare badly. The Midland Railway, however, and also the Great Western now build their waggons with a buffer system similar to that used for carriages. The buffer heads are attached to long rods, which bear against the two ends of a large laminated spring laid horizontally across the underframe outside the middle-bearer. The draw-bar is widened out, and a slot made in it, through which this spring passes, so that it acts against the traction as well as against the buffing strains.

"The outside dimensions of the body are, in general, left to the judgment of the builder. The Taff Vale Railway, however, specify that the capacity shall be between 240 and 245 cubic ft., and that the wheel base shall not be more than 5 ft. 6 in. This necessitates an exceedingly short and deep waggon. On other lines the wheel base is generally specified to be about 8 feet, and the length, especially in the North of England, is at least 13 ft., and often 14 ft. or upwards. The Taff Vale type, though perhaps exaggerated, represents much more nearly what should be aimed at; the advantages of short waggons being manifold. In the first place, they effect a considerable saving in weight and cost. The sheeting is of course nearly the same in any case, if the cubic contents are the same; but the sole bars, side rails, and diagonals are shortened, and so are the draw-bars, capping irons, and longitudinal tie-rods. Secondly, short trucks are handier in themselves, and require smaller turntables. Thirdly, they make up into shorter and handier trains. This last is an advantage of great importance when the enormous length of goods trains at the present day is considered, and also that such a train has usually to move its whole length twice, first past the points and then over them, in order to get into a siding. Fourthly, a short truck cannot fail, as a long truck often does, by the hogging of the sole-bars. Supposing a sole-bar to be uniformly loaded, and supported on axles 8 ft. apart, it should not overhang more than 2 ft. 10 in. at each end if the strain over the bearings is not to be greater than that at the centre; but considering the weight of the headstock, buffers, sheeting, &c., which are placed at the extreme end of the sole-bar, it would seem that 2 ft. 3 in. is a more fitting limit. This would give a length of 12 ft. 6 in.; and this, with a width of about 7 ft. 6 in. and a depth of about 2 ft. 9 in., will form the most suitable body for an 8-ton waggon. If there are no end doors, the two end planks may be curved with a rise of 5 in., and then the depth of the sides need not exceed 2 ft. 6 in.

2035.



2036.



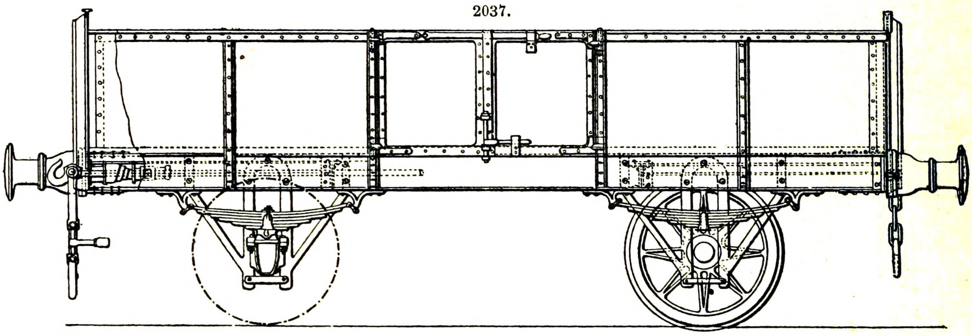
"The thickness of the planking has also to be considered. In general that of the bottom is $2\frac{1}{2}$ in., and that of the sides either $2\frac{1}{2}$ in. or 3 in. The top edge is protected by a capping iron or flat bar; but this bar being simply screwed down to the top plank, does not add to the strength of the waggon in any way. It would, therefore, appear feasible to transform this into a light angle iron, say 2 in. by 2 in. by $\frac{1}{4}$ in., which should be let into the top plank throughout its length, and bolted at each end to the corner plates, and also to the inside knees wherever they occur. There would thus be formed a sort of light wrought-iron frame for the body, which would materially strengthen it, and the thickness of planking might then be reduced to 2 in., or even less."

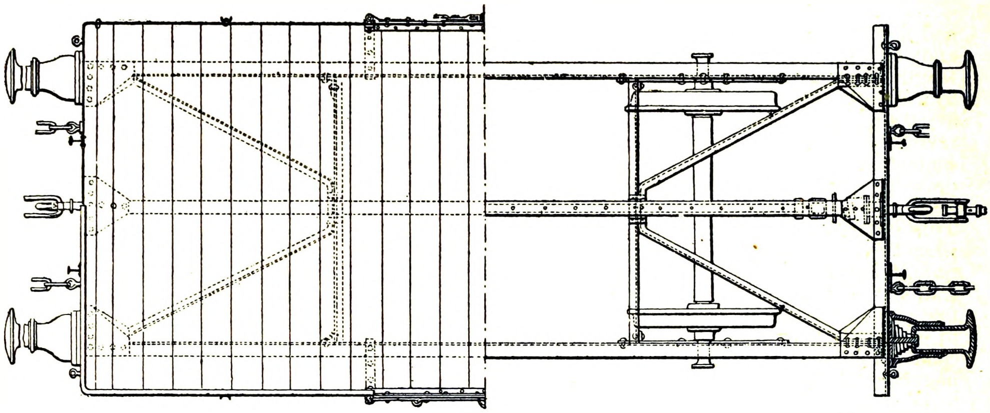
Fig. 2030 is a side elevation, Fig. 2031 an end elevation, and Fig. 2032 a plan of an ordinary 8-ton coal waggon, as built by the Bridgewater Engineering Company, to run on the lines of the Great Western Railway Company. The underframe of this waggon is entirely of oak, the sole-bars, headstocks, and middle-bearers being all 12 in. by 5 in., and the diagonals 11 in. by 3 in. The wheels, Fig. 2033, are 3 ft. in diameter, with eight pairs of wrought-iron spokes, and weldless iron or Bessemer steel tires, 5 in. by 2 in., secured to the skeleton by rivets. The axles are 5 in. diameter within the boss, and $4\frac{1}{4}$ in. diameter at the centre, the journals being 7 in. by $3\frac{1}{2}$ in. The bearing springs are 3 ft. 3 in. long by 3 in. wide, and consist of twelve plates each $\frac{3}{8}$ in. thick, and one plate $\frac{1}{2}$ in. thick. Its tare weight is about 4 tons 7 cwt.

Fig. 2035 is a side elevation, and Fig. 2036 an end elevation of a 10-ton goods waggon, with one end and side doors, constructed by the above company; the plan of the underframing and the general construction being similar to that of the 8-ton waggon above described.

In Figs. 2037 to 2039 is shown an iron coal waggon constructed by the Société Général d'Exploitation de Chemins de Fer, Tubize, Belgium; Fig. 2037 is a side elevation, Fig. 2038, a half end elevation and half cross section, and Fig. 2039 is a half plan of waggon and half plan of underframing. This waggon is fitted with side doors; and is constructed wholly of iron, with the exception of the floor, which is of wood.

2037.





2039.

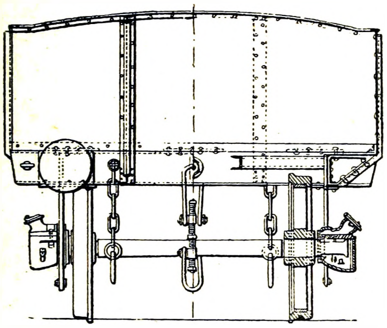
Its principal dimensions are ;—

	ft.	in.
Depth of underframe	0	$9\frac{1}{3}$
Width ,, ,, ...	6	$6\frac{1}{3}$
,, of channel irons forming underframe	0	$3\frac{1}{3}$
Width of centre channel iron ..	0	3
Diagonals .. .. .. $1\frac{3}{4}$ in. by $\frac{2}{5}$ in.		
Middle bearers .. $2\frac{2}{5}$ in. by $\frac{2}{5}$ in.		
Distance between centres of buffers	5	$8\frac{9}{10}$
Diameter of buffers	1	$2\frac{2}{5}$
Height of centre of buffers above rails	3	6
Distance between centres of safety chains	3	6
Length of body	18	$0\frac{1}{2}$

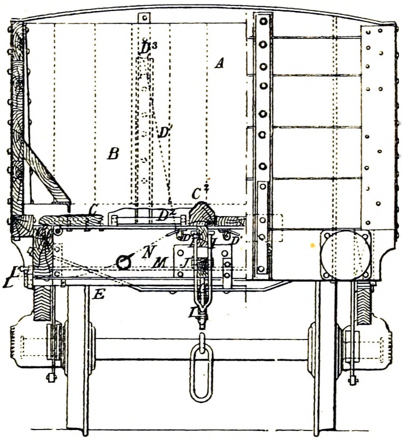
	ft.	in.
Width of body	8	$3\frac{1}{4}$
Height of body inside at centre ..	3	$1\frac{2}{5}$
,, ,, sides ..	2	$9\frac{1}{2}$
Thickness of bottom plankings ..	0	2
Width of doors	4	11
Diameter of wheels—about	3	$2\frac{1}{2}$
Width of tires	0	$5\frac{1}{3}$
Distance between centres of wheels	9	$10\frac{1}{9}$
,, ,, ,, journals	6	$3\frac{3}{5}$
Length of journals	0	$6\frac{4}{5}$
Diameter of journals	0	$3\frac{1}{3}$
,, at back of journals ..	0	$4\frac{2}{3}$
,, of wheel seat	0	$5\frac{1}{9}$
,, at back of wheel seat ..	0	$5\frac{1}{3}$

An improved construction of hopper, coal, or mineral waggon, by R. Morton, of Newton Heath, Manchester, is shown in Figs. 2040 to 2042; Fig. 2040 is partly a side elevation and partly a longitudinal section, Fig. 2041 partly a cross section and partly an end elevation, and Fig. 2042 a plan of waggon and framing. The object of this invention is to enable the bottom doors of hopper, coal, and other railway waggons, to be opened or closed simultaneously, without the attendant having to go beneath the waggon, or from one side to the other, as hitherto practised; and the means by which this is accomplished will be readily understood from the drawings and the following description. A is the body portion of the waggon, and B the hopper, at the bottom of

2038.

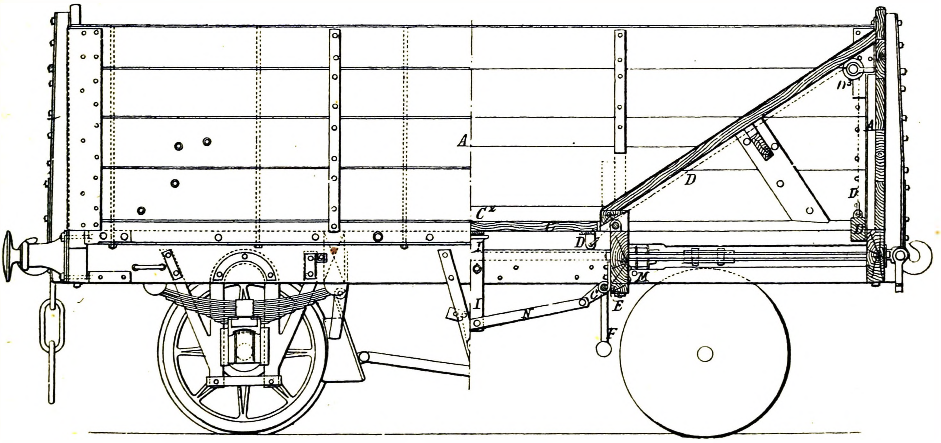


2041.



which and opening downwards are the double doors C, hinged to the sole-bar C' in the ordinary manner, and both closing against the one common central or longitudinal bar C''. These doors have imparted to them, by means of the chains D, a constant tendency to close; the chains D being connected to their hinges D', and passing over the rollers *r* and pulleys *p*, and having counterbalance weights attached to their extremities. A shaft E is mounted transversely across the

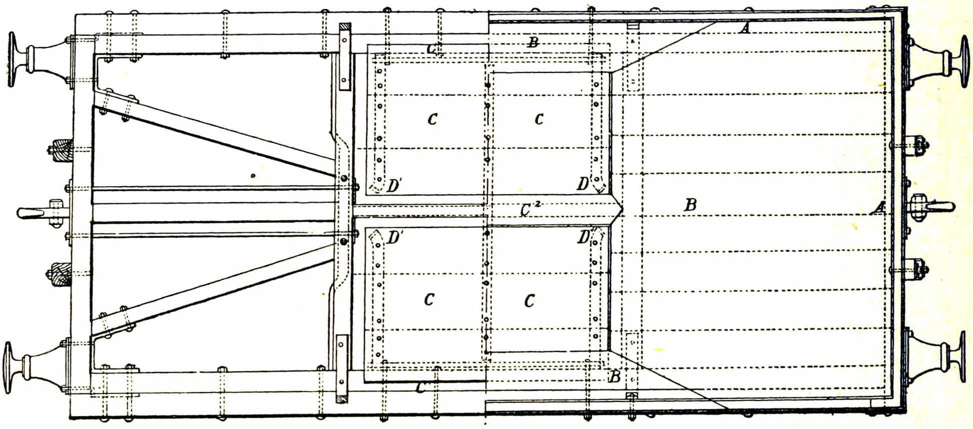
2040.



under side of the waggon, and to each end of this shaft is keyed an actuating lever F, so as to enable such shaft to be worked from either side of the line of rails. On the shaft E is an arm G, which is connected by a link H to a forked lever I mounted on a bolt J passing through the underneath longitudinal bar K. The short arms I' of the lever I are designed to hold both the doors C in the closed position, as will be seen by reference to Fig. 2041. In order to fasten the doors C in either the closed or open position, a suitable drop catch L is applied on either side of the waggon, such catches being secured at opposite extremities of a shaft M passing through the framework from one side of the waggon to the other, these catches L being each provided with a slot to catch on to one or the other of the two shorter arms F' of the actuating lever F, according as to whether it is desired to retain the doors C in the open or closed position.

Assuming that the doors C are closed, as shown in the drawings, and it is desired to open them, all that is requisite is for the attendant to lift the drop catch L by means of its handle L', and then to pull the actuating lever F on one side, until the drop catch falls on to the other shorter arm F' of the actuating lever F, when the doors C will immediately open by reason of the weight of the materials lying upon them, and thus the contents of the waggon will be discharged. In order to secure the doors C remaining open meanwhile, and to counteract the closing tendency imparted by the weights W, a length of chain N, is attached to each of the doors, the said chain being provided with a ring O capable of being hooked on to a hook R, secured to the framework of the waggon. The waggon having been thus emptied, the ring O is removed from its hook, when the balance weights W will be free to close the doors, and the same may be locked in the closed position by once more releasing the drop catch L, and allowing it to grip the other shorter arm F′ of the actuating lever F. And all of these movements can be regulated from either side of the waggon, without the attendant having to pass either under the waggon or from one side to the other, whereby the safety of the attendant when discharging these trucks is greatly increased.

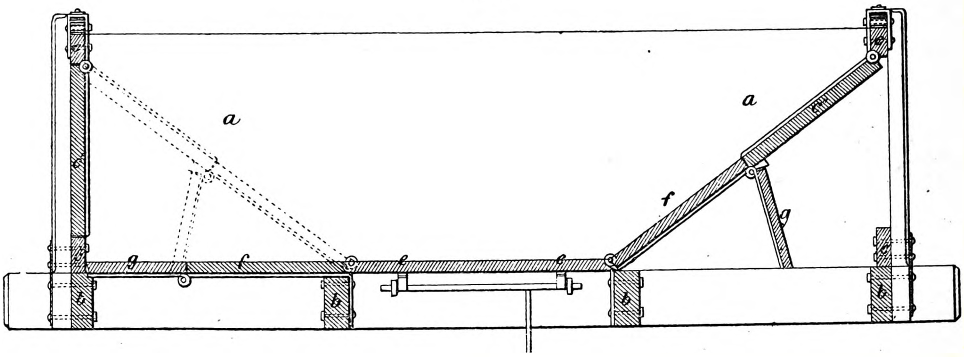
2042.



A modification of this invention, to enable the bottom doors of railway waggons to be opened and closed simultaneously from either side of the waggon, consists in the shaft E being provided with a pair of arms, one for each door, the extremities of which arms are designed to move along the outside of the bottom doors, and thus not only to raise and close the same, but to hold them in the closed position, this modification being however only applicable to waggons with small doors, and which are sufficiently light in weight to be lifted by one man.

In Fig. 2043 is shown a longitudinal section of another construction of coal or mineral waggon, by Simon Leach, of Chorley, Lancaster, which may be used either as an ordinary vertical-sided waggon with a carrying capacity of 10 tons, or as an 8-ton hopper waggon.

2043.

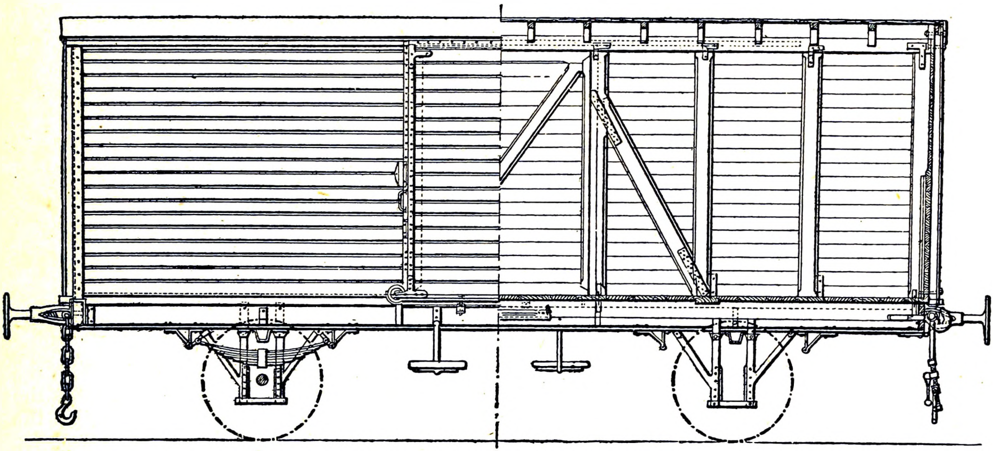


This waggon is constructed with fixed vertical sides A in the usual manner, the underframe being provided with four cross bearers B. The upper and lower parts only of the ends C are fixtures, the central part of each end being formed into a hinged flap C′. The central portion E of the bottom, between the two central cross bearers B, is made with either one or two doors to open downwards for discharging the contents, as in the ordinary hopper waggon. The end portions are each made of two pieces F and G, hinged together, the inner piece F of each being also hinged to one of the inner cross bearers B, so that it can be lifted up so as to form a portion of the sloping end of the hopper, as shown at the right hand of the figure, the other piece G, hinged thereto, forming, as it were, a strut or support to keep it in this position, a hook and staple, or bolt, being provided to hold it firmly. The continuation of the slope to the end of the waggon is made by the portion C′ of the end, which is hinged at its upper side to the vertical end C, and is so arranged that, when raised, it can rest on the hinged piece G, forming the strut or support, and it will then form, with the piece F, a continuous slope from the bottom to the upper part of the end of the waggon, so as to assume the form of a hopper waggon.

When the waggon is to be used as an ordinary vertical-ended waggon, the end flaps C′ are allowed to hang down vertically, and, the hook being removed from the staple, the hinged parts F and G, of the bottom fall down flat and level with the central doors E; the ends are then vertical, as shown at the left hand of the figure, and the bottom is horizontal and level from end to end.

A covered goods waggon, Figs. 2044 to 2046, of a very useful type, is one which, with slight modifications, is very largely in use on continental lines. This waggon was constructed by the Railway Rolling Stock Construction Company, Breslau, and is intended to carry a load of 10 tons, the weight of the waggon when empty being 6 tons 8 cwt., equal to a load of 1 ton 11·25 cwt. a ton of dead weight, or a dead weight of 12·8 cwt. a ton. Fig. 2044 is a half side elevation and half longitudinal section; Fig. 2045 a half end elevation and half cross section; and Fig. 2046 a quarter plan of roof, a quarter plan of flooring, and a half plan of framing.

2044.



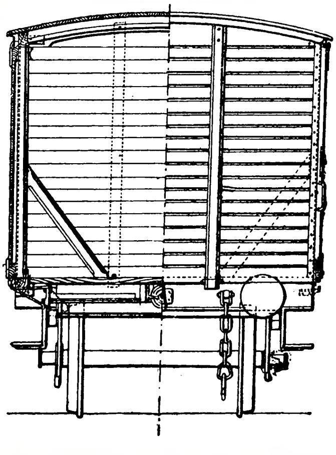
The principal dimensions are;—

	ft.	in.
Length outside	23	$7\frac{1}{2}$
„ inside	23	$4\frac{3}{8}$
„ over buffers	27	$2\frac{3}{4}$
Width outside	8	$6\frac{1}{3}$
„ inside	8	$4\frac{3}{8}$
Height inside at centre	7	4
„ „ sides	6	11
„ of doorways	6	$6\frac{3}{4}$
Width „	4	11
Height of centres of buffers above rails	3	$5\frac{1}{7}$

		ft.	in.
Distance between centres of sole plates		6	$5\frac{1}{8}$
Diameter of wheels		3	$2\frac{5}{8}$
Wheel base		13	$1\frac{1}{2}$
Sole plates ..	$9\frac{3}{8}$ in. by $3\frac{1}{2}$ in.		
Headstocks ..	$9\frac{3}{8}$ in. by $3\frac{3}{8}$ in.		
Longitudinals and transverse bearers	$5\frac{3}{4}$ in. by $2\frac{1}{2}$ in.		
Diagonals	2 in. by 2 in.		

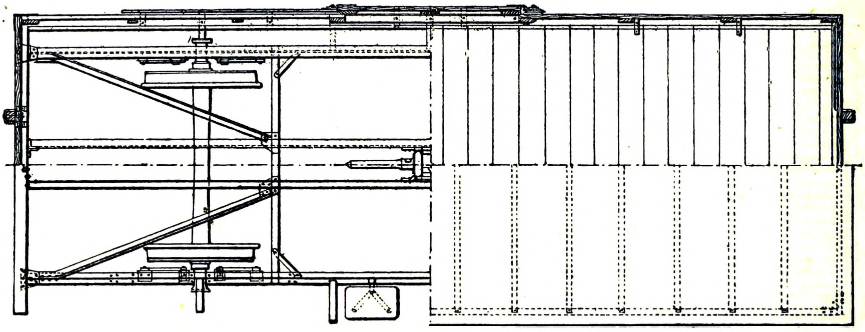
The underframe of this waggon is entirely of iron, the soles being formed of I irons, the headstocks, longitudinals, and transverse bearers of channel section, and the diagonals of angle iron: the manner in which the various parts of the framing are connected by gusset pieces, being clearly shown in the plan, Fig. 2046. The wheels are solid Krupp steel discs, and the horn plates have rubbing pieces riveted to them to fit the axle boxes, a plan common in continental practice. The draw-bar is continuous with a volute draw-spring, and the buffers are outside, with volute springs contained in wrought-iron skeleton cases. The body is carried at the sides by wrought-iron brackets, riveted to the outer sides of the soles; and the framing, which is of oak, is light but stiff. The side and corner pillars are about 6 in. by 1 $\frac{1}{2}$ in., and the diagonals are of the same scantling. The flooring is of 2 in. planking laid transversely and lap-plated, while the side planking is of 1-in. boards, tongued and grooved, and fixed outside the pillars. The end planking, which is also tongued and grooved, is placed inside the pillars, and is $1\frac{9}{16}$ in. thick for about half the height of the waggon, and 1 in. thick for the remainder. There is no transverse framing at the bottoms of the ends of the body, but the end pillars are each held at the bottom by a strap riveted to the upper flange of the headstock, and by a bolt passing through a corner knee which is also riveted to the headstock. At their upper ends the end pillars are bolted to the outer side of the arch rail instead of being framed into the latter, as is the usual practice in this country. The ends are stiffened transversely by diagonals, placed inside the planking and extending from the corner pillars, at a little below the middle of their height, to the floor, at about a third of the width of the waggon from the sides, as in the cross section, Fig. 2045. The sliding doors, on each side of the waggon, are carried by rollers, running on suitable rails, which are supported by the wrought-iron brackets above referred to.

2045.



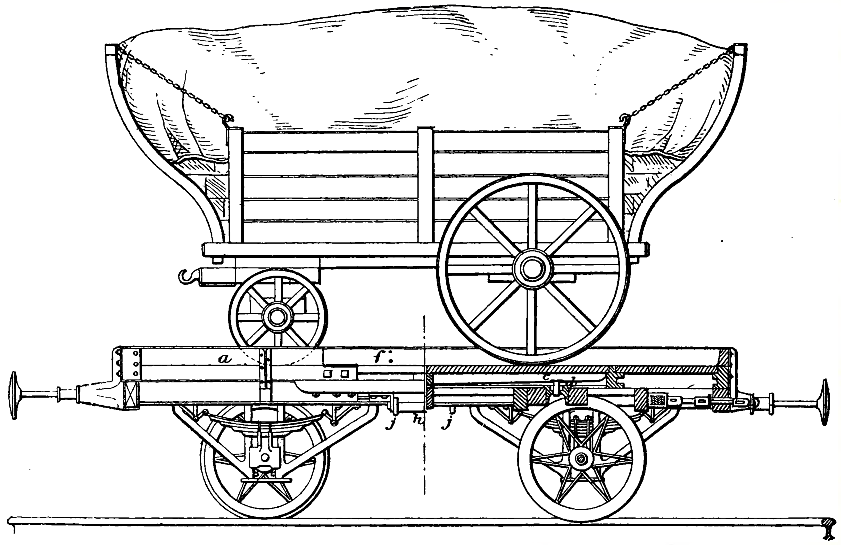
In Figs. 2047 to 2050 is an improved railway waggon, with a movable platform, to facilitate the loading and unloading of loaded vehicles, by Henri Entz, France. Fig. 2047 is one of these platform waggons in elevation, closed on the left side, and open in vertical section through the longitudinal axis on the right. Fig. 2048 is a cross section, the waggon being open. Fig. 2049 a plan of different parts of the waggon; A is a plan of the frame of the turntable, the waggon being open; B a plan showing the waggon closed; C a plan of the underframe; and D a plan with the turntable removed; and Fig. 2050 is a cross section of the waggon closed. In Fig. 2047 the waggon is loaded with an army stores road-carriage, and in Fig. 2048 it is discharging the same.

2046.



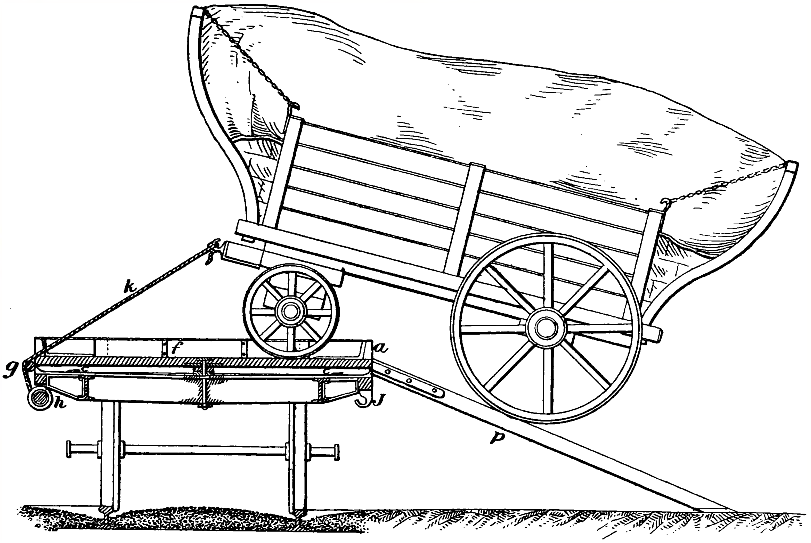
It will be seen from the drawings that the usual woodwork is unaltered, the planks *a* alone being cut for access to the platform, which turns at the centre upon an axis *b*. The platform *p* is of wood, its floor being level with that of the waggon; it is mounted on a special frame, furnished with a circular iron hoop *c*, which turns upon a line of rollers *d*, which are supported by the waggon frame. As the diameter of this platform is superior to the breadth of the waggon, the former is cut on four sides, the said sides being, two and two, parallel and at right angles to each other. Two of these sides are furnished with wooden pieces *f*, whose dimensions are sufficient to fill up the spaces made in each of the side planks, and these pieces *f* form the continuation of the said side planks when the waggon is closed. The other two sides, at right angles to the first, leave a space in the middle of the floor, which is filled up by plates of sheet iron fixed by hinges either to the floor of the waggon or to that of the platform. These latter sides are also furnished with holes and irons *i*, for hooking on the ladders, or other equivalents, for running the loaded vehicles on and off the waggon. In the sides of the platform are hooks *i*, in which the ends of the rollers *g*, which guide the drawing rope *k*, are placed; this rope is coiled or let out by means of a drum *h*, which is placed either on the right or left of the waggon, as the case may require, and is supported by the hooks *j*, which are bolted beneath the body of the waggon. As shown in Fig. 2048, the drum *h* delivers the rope *k*, or winds it, according as the vehicle is being loaded or unloaded, and before fastening to the carriage this rope passes over one of the rollers *g*. The drum *h* is intended to be actuated by means of a rachet lever, as being the most simple arrangement; but any other form of windlass may be employed if preferred.

2047.

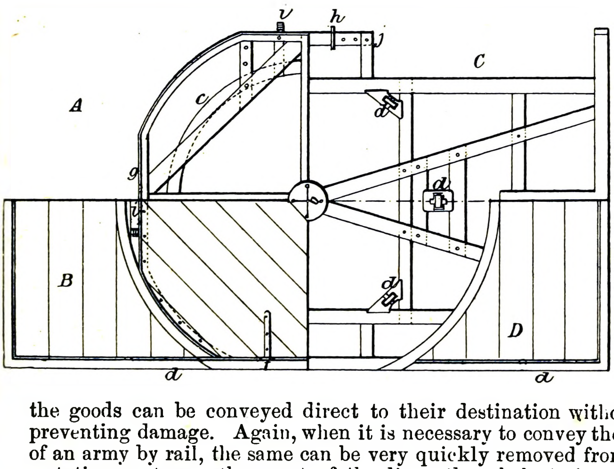


The waggon is opened to receive or discharge the loaded vehicle by giving a quarter turn to the platform, and it is closed by giving a further quarter turn, or by returning it to its former position; which latter movement brings the vehicle into a position parallel with the line. The advantages claimed for this waggon are as follows. By its use the time and labour expended in loading or unloading railway waggons with road carriages are greatly reduced, as the loading or unloading can be carried on at any part of the line, without its being necessary to shift the waggon to a special part of the line in the manner now adopted; also, as each waggon contains a turntable in itself, the labour of turning the waggon bodily, as is now so often necessary, will be altogether saved. A second advantage is, that in industrial works and factories, when this system is adopted, the waggons can be loaded with merchandise, by the aid of a windlass, in the manner Fig. 2048, without the necessity of providing quays or platforms for the purpose; and by these means the goods can be conveyed direct to their destination without unloading, thus saving time and preventing damage. Again, when it is necessary to convey the stores, baggage, provisions, or guns, of an army by rail, the same can be very quickly removed from or placed on the waggons, either at a station or at any other part of the line; the whole train of waggons being loaded or unloaded simultaneously, there being no necessity to bring them alongside any quay or platform.

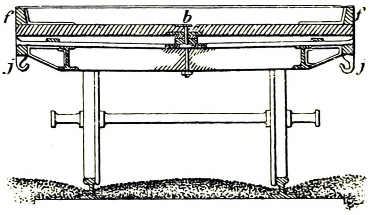
2048.



2049.



2050.

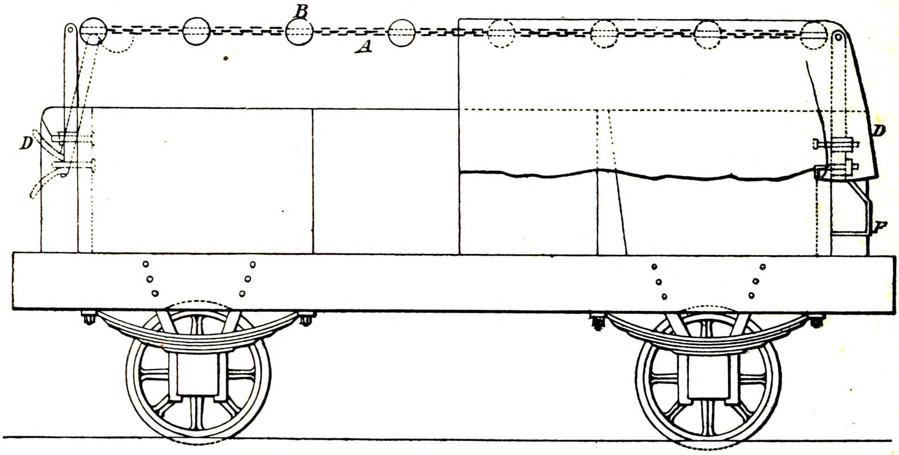


One great item of loss experienced by railway companies, in connection with the goods traffic, arises from the damage which is sustained by waggon sheets under the general method of employing them, and the consequent loss which arises under the head of compensation for damaged goods, the loss under these two heads amounting to several thousand pounds a year to each of our principal railway companies. It is, therefore, certain that any simple and efficient apparatus, which is capable of reducing the wear and tear of waggon sheets to a minimum, while at the same time effectually preventing the damage of the goods by wet or other causes, is sure to be welcomed by the managers of railway goods departments, and to receive a fair trial.

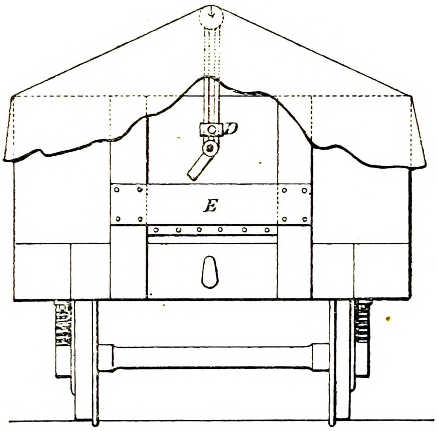
The principal cause of the undue wear and tear of waggon sheets consists in the manner of their employment. With the ordinary flat waggon it is usual to stretch the cover tightly across from side to side, and from end to end, the principal tying being done at the corners; and, therefore, unless the goods in the waggon are of such a form that they give support to the sheet, the latter sags towards the centre from every direction, and in wet weather forms a water tank if the sheet be good, or simply directs the water on to the goods if the cloth be bad; while, if the sheet be good, it is soon destroyed by the strain at the corners due to the weight of the water, or even of the sheet itself. Sheets are also frequently damaged in the central parts by their sagging down on to goods of a rough character, and are often torn in pulling them over the corners, or off one side of the truck for unloading. Principally to secure a means of support for the sheets many waggons are made with gable ends, a pole being placed from gable to gable over the goods. The waggons, however, in this way are made more expensive, while the pole is very often not used.

Walker's waggon sheet protector, Figs. 2051 to 2055, is one of the most simple and efficient that could be devised. A waggon fitted with this apparatus, Fig. 2051, has one half covered with the sheet; Fig. 2052 shows an end elevation of the waggon covered; Fig. 2053, the waggon with the supports lowered and the chain placed in the box E provided for that purpose; and Figs. 2054 and 2055 show the supports and chain to an enlarged scale. The support C, Fig. 2054, consists simply of a bar of flat iron, bent round into a flat link, the upper end carrying a pin, to which the chain A is fastened by one of the long links upon which the wood balls B are threaded. This support is held loosely in the staple pieces D, fixed by means of a bolt which passes through it and the support; a second bolt, fitted with a hand nut, being placed below the staple; and by means of this bolt the support is fastened at any desired vertical height. To stretch the chain across the waggon, the support to which the chain is permanently fastened is fixed by the hand screw; the chain is then carried across to the other end of the waggon and hooked to the other support while the latter is loose, and capable of canting inwards, as indicated by the dotted portion at the uncovered end of Fig. 2051. As soon as the chain is hooked on, the hand screw is tightened up, and the chain thus stretched tight. The sheet may then be thrown over and fastened. The fastening does not require to be so tight as is usual, as there is no opportunity for the cloth to sag, and as it may move to a slight extent, and without injury, by rolling over the wooden balls B.

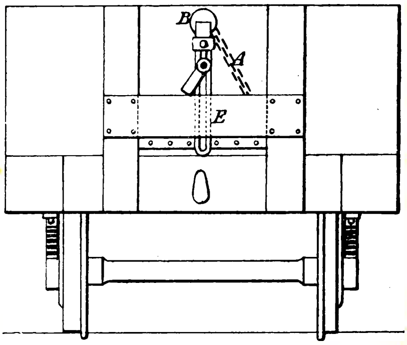
2051.



2052.

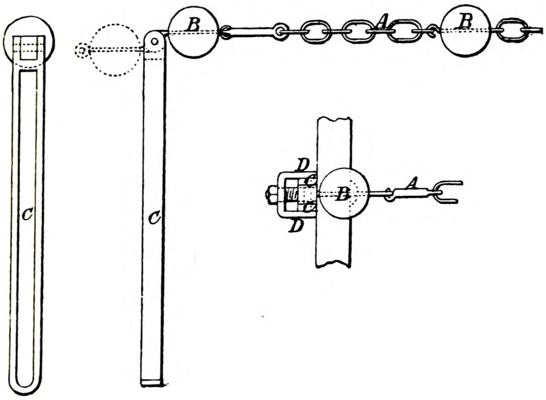


2053.



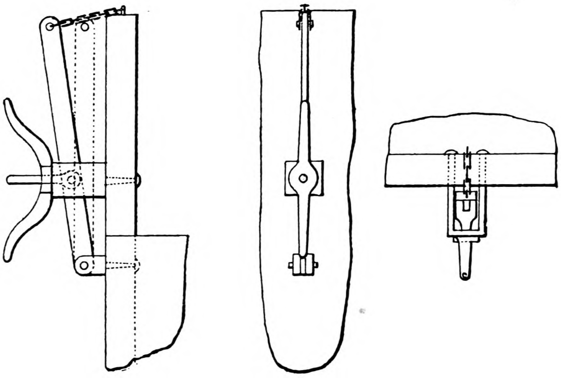
Another simple apparatus of the same description is Ward's, Figs. 2056 and 2057; Fig. 2056 being a side elevation, and Fig. 2057 an end elevation, of an ordinary goods waggon fitted with this apparatus, and its construction and mode of action will be readily understood from the following description. This apparatus consists of a novel arrangement of bows for the purpose of forming a tilt, upon which the waggon sheet may rest in a sloping position, the said bows being so constructed as to fold back, over or beyond the ends of the respective trucks, when not required for the purpose described. The radial arms A of the bows A^1 are hinged or pivoted at the side of the waggon, as shown at B, the said arms being elbowed at D. When these bows are required to support the waggon sheet, they are placed in position across the waggon, as shown at A^1, Figs. 2056, 2057; but when the sheet has been removed, and the whole clearway of the waggon top is required for loading or other purposes, the said bows, being free to revolve upon the pivots or axes at B, Fig. 2056, are turned upon the pivots towards the end of the waggon until they fall beyond it, as at C, the bows being supported in either position by the hooks E.

2054.

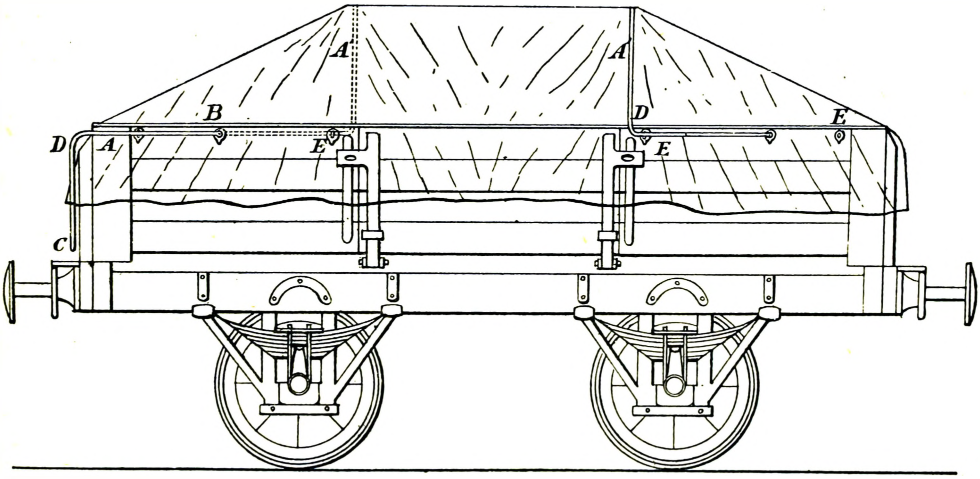


American Rolling Stock.—The rolling stock employed on the lines of the United States differs considerably, in many important points, from that of English and of continental lines. In the first place rigid wheels and axles are scarcely ever employed, the vehicles, whether for passengers or goods, being carried on four or six-wheeled bogie trucks; the latter being specially employed for heavy sleeping and drawing-room, or as they are called in the States, parlour, cars; and it is generally conceded that the cars and waggons so mounted are steadier and smoother in their running than those otherwise mounted; and this opinion is gaining in England, as bogie carriages have during the last few years largely increased in number. A second great difference is in the internal arrangements of the passenger cars; all of these, whether day or sleeping cars, being arranged with a central longitudinal passage, which by means of the end platforms, the cars being always close coupled, affords a means of communication and circulation throughout the whole length of the train. This, though obviously possessing many advantages, is, however, an arrangement which is not likely to meet with general favour in Europe, as it would do away with all that semi-privacy which has hitherto been enjoyed when travelling, and which by a majority is preferred, even to the slightly more public saloon

2055.

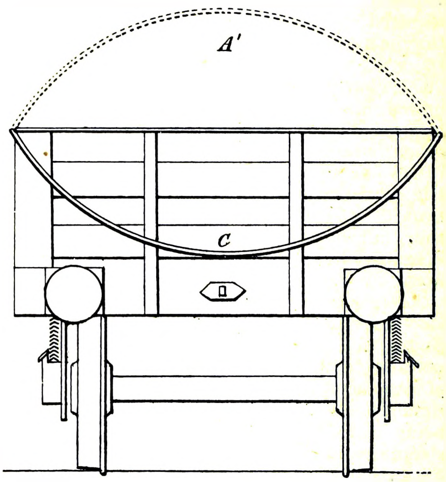


2056.



carriage. A great disadvantage possessed by this central passage arrangement is, that the only doors being at the ends, and the only means of egress being by these doors and the end platforms, a passenger on arriving at his destination may have to traverse half the length of the carriage before being able to alight. Another great difference is in the size of the carriages, the American passenger cars being all considerably longer and higher, a passenger car seating from fifty to sixty passengers; and the goods waggons being also much larger; the proportion of dead weight to paying load being much higher in both cases than in England. Great advances have, however, been made in this respect during the last few years in the matter of goods waggons, as shown in the report lately issued by the Western Weighing Association. From this report it appears that during six weeks nearly 50,000 cars were weighed, and while the average of the different classes of freight ranged from 23,750 lb. for machinery to 29,925 lb. for ore, the maximum in nearly all cases exceeded 30,000 lb., and for some classes of freight reached, respectively, as high as 35,000 lb., 37,750 lb., 39,300 lb., 39,600 lb., and even, in the case of ore, to the great weight of 48,500 lb., or nearly 22 tons. The average weight for the whole being about 12 tons a car, as against 10 tons, which was the maximum load but a few years ago.

2057.



The internal fittings of a first-class American car are good, but inexpensive. A large amount of admirably made cabinet work in choice wood is generally found, the roof and top side linings being of painted canvas stretched on frames; mirrors are introduced, and at each end is a lavatory and stove; filters, the water of which is iced in summer, being also provided. The seats are generally upholstered in velvet, and each holds two passengers; these seats are hung on centres, and can be turned, so that the contents of the car may be divided into groups of four, sitting opposite or all in one direction.

Nominally there are but two classes on American railways, namely first-class passengers and emigrants; but in reality there are three, as clearly, or even more clearly, defined than in Europe, and this without taking into account the emigrant traffic, the accommodation which is provided for these latter being of the most meagre description, and but barely sufficient to enable them to perform their journey, anything like comfort being altogether unthought of. First we have the ordinary first-class cars, which are well-appointed, commodious vehicles, in which, however, a general absence of proper means of ventilation, together with the continual presence of tobacco smoke, combine to produce an atmosphere altogether peculiar to these cars, and rendering them, to the majority of travellers, anything but desirable places in which to undertake a long journey. Next the so-called ladies' cars, which form practically a separate class, as gentlemen unaccompanied by ladies are not admitted to them; but in these also, although smoking is prohibited, the want of proper ventilation, especially in winter, is very much felt. The third class consists of the special vehicles either belonging to the company, or hauled by them, admission to which is gained by payment of an extra fee; the greater number of these special cars being owned by the Pullman Palace Cars Company. In these the accommodation leaves nothing to be desired, and though privacy, which is recognised elsewhere as an advantage, does not exist, the traveller enjoys a lofty, roomy, and luxuriously fitted vehicle, which travels with the utmost smoothness, which is kept cool in summer and is well warmed and ventilated in winter, and in which a freedom of personal movement is practicable. Besides the parlour cars and sleeping cars, there are others which are fitted up as dining or restaurant cars.

The rolling stock employed for the goods traffic, in common with the passenger stock, also differs considerably, and is of a very varied and, in some cases, special character; the chief features of the various types being the end bogie cars, and their great size and weight.

In Figs. 2058 to 2061 is illustrated a standard first-class car of the Pennsylvanian Railroad, having accommodation for fifty-four passengers. In Fig. 2058 at 1 is a side elevation of the body of the car, at 2 a side elevation of the body framing, at 3 a sectional view of the framing, and at 4 a longitudinal section of the interior of the car; Fig. 2059 is a half end elevation and half cross section of the body; Fig. 2060 is a half elevation and half section of the end framing; and Fig. 2061 is a part plan of the underframe; and Fig. 2061* a part plan of the interior of the car. This car is carried upon two four-wheeled bogie trucks, which are placed 28 ft. 1 in. apart from centre to centre.

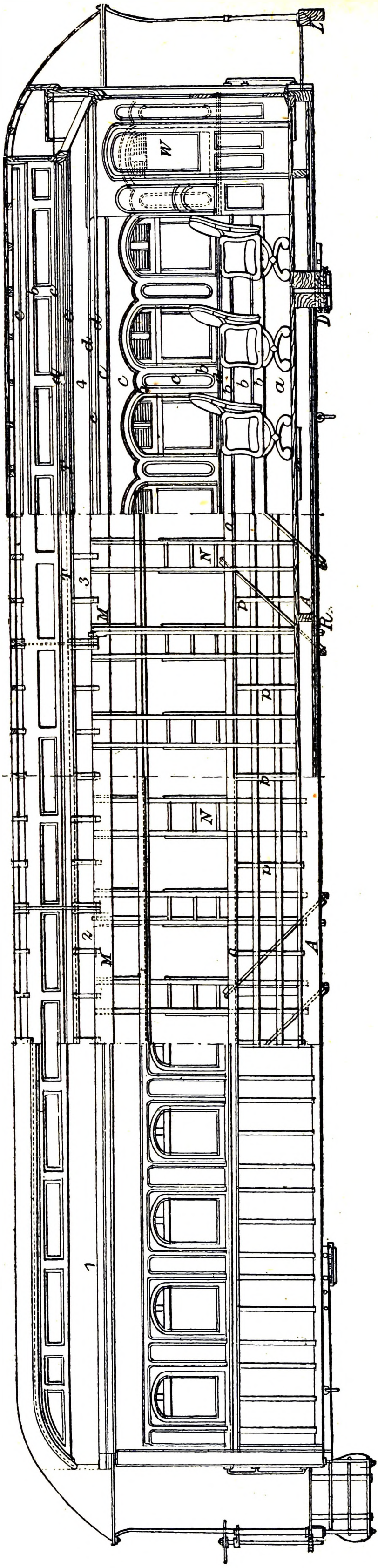
The principle dimensions of this car are;—

	ft.	in.
Length of bottom frame	46	6
„ „ between shoulders	45	8
Width of „ „	9	$4\frac{3}{4}$
Total length over end platforms	51	6
Length of body inside	45	$2\frac{3}{4}$
Width „ „	8	$6\frac{1}{4}$
Height inside, to top of side framing	6	$9\frac{1}{2}$
„ „ to springing of raised portion of roof	7	9

	ft.	in.
Height inside, of raised portion of roof	9	6¾
Width „ „ „ at bottom	4	6
„ „ „ „ at top	4	2
Length „ „ „	41	8¾
Width outside of raised portion of cover of roof	5	6
Height of end doors	6	6
Width „ „	2	1
Height of window openings in frame	2	8⅜
Width „ „ „	1	10¾
Height from rails to under side of body	3	5¾
Total height above level of rails	13	10¼
Extreme outside width	9	8
Diameter of wheels	2	9
Weight of body unloaded	about 17 tons 11 cwt.	
„ four-wheeled truck	„ 2 „ 17¼ „	
Number of passengers carried	54	

The framework of this car consists of a braced structure, in which the sides form an important feature. The principal members consist of two sill timbers A, 8 in. by 5 in., running the whole length of the car, and placed 8 ft. 6¾ in. apart in the clear; the end timbers B, the corners of which are rounded, being of the same scantling. At each of the four inner corners of this frame are fixed cast-iron brackets C, by means of which the longitudinal and transverse sills A B are secured together. The principal transverse framing occurs at the points where the cast-iron turning plates D are bolted, which take their bearings on the bogie truck; it is formed of two beams, one 7 in. deep and the other 5 in., both being 14 in. wide. The lighter beam passes across between the outer sills, the deeper one being placed only between the inner longitudinals E, which are parallel with the outer ones, and are 4½ in. wide and 7 in. deep. A pair of straps F, shown in Fig. 2061, are stretched over the top of this middle transverse timber, their ends being attached to a couple of tie-rods, which pass through the lower transverse beam, and are secured by nuts, the ends of the beam being chamfered so as to secure a fair bearing, and washer-plates being introduced. The space between these transverse frames for the truck bearings is divided into three bays, two of 10 ft. 4¾ in., and a central one of 10 ft. 7½ in. Transverse timbers G, 5 in. by 3 in., extend across and beneath the outer sills, while above these are lighter stretching pieces H, placed between the four inner longitudinal timbers; tie-rods, which are secured to the outer sills, running close beside these cross beams. In addition to this, a system of horizontal diagonal bracing I is introduced, there being five panels of this in the whole length of the car. In addition to the main frame there is, at each end, an auxiliary frame K, for carrying the Miller platform. These frames consist each of four timbers 5 in. by 3½ or 4 in., which are carried back to the truck beams, and project about 2 ft. beyond the main frame; and at their outer ends these timbers carry a beam L. The total width of this auxiliary platform is 4 ft. 11 in., the middle pair of timbers being 8 in. apart in the clear, and the outer ones 1 ft. 6 in. distant from the inner. Planking is laid upon these timbers, from the outer pair of which steps descend leading to and from the car; to the end beams are attached the rails forming the platform guard, two standards from which rise to the projecting roof of the car, the hand-brake gear being also attached here. The steps on each side are three in number, with 8-in. treads, and 10½-in. risers; decreasing from 2 ft. 10 in. wide at the bottom, to 2 ft. 1 in. at the top, and rest upon cast-iron brackets bolted on the inner side to the frame direct, and supported outside by a light bracketed standard, descending from the under side of the frame and passing through the bottom step. Bolts *a*, 1 in. in diameter, pass from the end beam to the main timber of the frame, the platform timbers being also bolted through to this beam. Besides the railing constituting the platform guard, which is 2 ft. 1 in. high, with an open space in the middle of the same width to allow of passing from one car to another, handrails are attached to the ends of the carriage, near each set of steps, to assist passengers in leaving or entering.

The side frames of the car are so built as to add very much to the strength of the structure. At a height of 6 ft. 10¾ in. above the longitudinal sills, and 9 ft. 3½ in. apart outside, two timbers M, 7 in. by 1⅛ in., run the whole length of the car. Groups of posts N, two in each group, being placed between the longitudinal sill and these upper timbers. These posts are 1¼ in. square, they are placed 10 in. apart, with a clear interval of 1 ft. 10½ in. between each group, and they are mortised into the sills, and attached to the upper timbers, which are placed outside them. The windows of the car are introduced into the openings of 1 ft. 10½ in. between the groups of posts, and each pair of the latter are connected and strengthened by light horizontal stretchers placed between, at intervals of 7 in. above the main horizontal rail O, which is placed 2 ft. 1⅝ in. above the sill A. The rail O is 3 in. by 4 in. and passes outside the groups of posts N, and the space between it and the sill A is divided into three parts by two other horizontal rails, each 2 in. by 1¼ in., which pass inside the posts and are bolted to them. Between the sill A and the rail O an intermediate post P is introduced between each group of posts N, and diagonal bracing rods are employed between the rail and the sill to strengthen the structure; there being twelve of these rods divided into four groups on each side of the body, the end pairs forming two groups being placed so as to fall from the rail O towards the end of the car, while the other four in each group are directed towards the centre of the car. Cast-iron bearing blocks are introduced, both on the top of the rails O, and underneath the sills A, for the adjusting nuts of the braces to take their bearings on, posts Q, 4 in. by 1¼ in., being placed between the rail and the sill wherever these braces occur. In addition to these diagonal braces, vertical rods R pass from the sill A to the upper timbers M, to which they are fastened by means of a sole plate and two bolts, there being six of these rods on each side of the car. At a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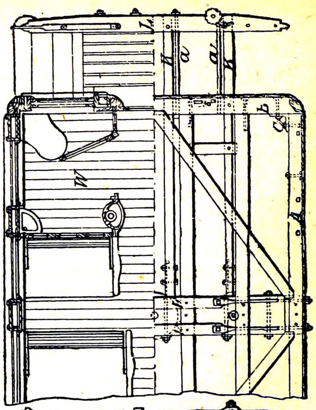
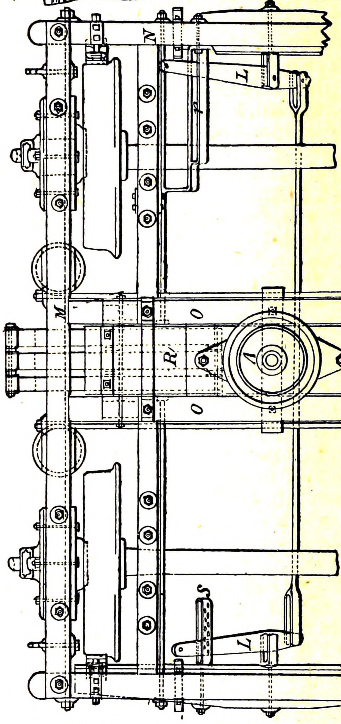
d
e
f
1
2
3
4
M
N
p
A
R

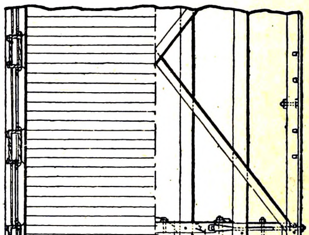
2058.



2061*.



2062.



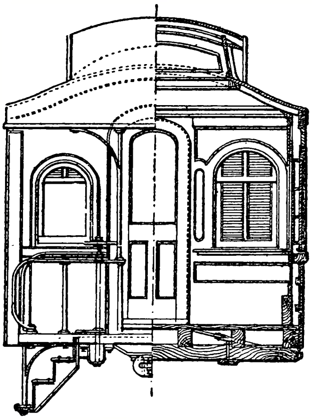
2061.

height of 2 ft. $9\frac{3}{8}$ in. above the rail O, a moulded rail S, $3\frac{1}{4}$ in. deep, runs horizontally from end to end, outside the group of posts, the clear space of $10\frac{1}{2}$ in. between this rail and the upper timber M being filled in with a panel the whole length of the car. The end framing of the car is similar to that of the sides.

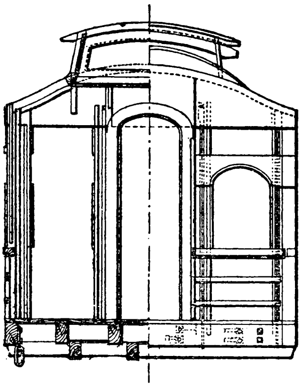
The floor of the car is formed of close planking $1\frac{1}{4}$ in. thick, the ends being flush with the outside of the main longitudinal sills, and cut away where the side posts interfere.

The outside of the sides of the body, as high as the moulded rail running beneath the sashes, is close-timbered with $\frac{5}{8}$-in. planking, tongued and grooved; but in order to break up the flatness of so large a surface, vertical strips are laid on at small intervals, and in the centre of the car there is an oval inclosure for its name and number. The window sashes have elliptical heads, and are surrounded with moulded rails, the spaces between them, corresponding with the groups of posts N in the frame, being filled in with sunk panellings.

2059.

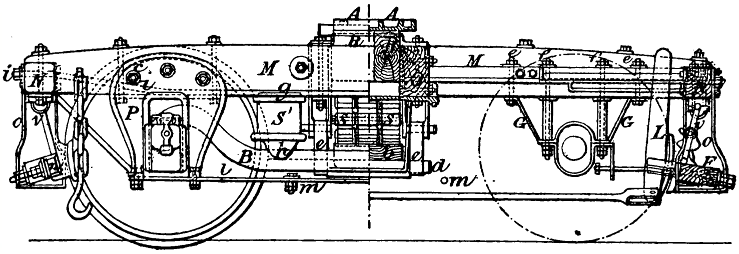


2060.



The roof is made with a raised portion or "dome" along nearly the whole of its length. This dome is based upon a rectangular frame of moulded timber T, 4 ft. $10\frac{1}{2}$ in. wide by 41 ft. $8\frac{3}{4}$ in. long, the under side of which is 7 ft. 9 in. above the floor of the car, this frame being supported by a series of half rafters, curved to the form required for the roof, $2\frac{1}{2}$ in. by $1\frac{1}{2}$ in., and placed 1 ft. $4\frac{1}{2}$ in. apart, with the exception that at six points in the length of the car these rafters are placed in pairs close together; the outer ends of these rafters resting on the longitudinal timbers M, and their upper ends mortised into the base of the dome. The sides of the dome are 1 ft. $3\frac{1}{2}$ in. high, formed of two moulded timbers, the lower one 2 in. by $1\frac{1}{8}$ in., and the upper one $5\frac{1}{4}$ in. by $1\frac{1}{8}$ in.; these are placed $7\frac{1}{4}$ in. apart, and are connected at intervals by vertical posts, so as to leave rectangular openings 2 ft. 8 in. by $7\frac{1}{4}$ in. down the whole length of the car, these openings being filled in with glazed swinging sashes, which act as ventilators. Into the timbers forming the upper part of the sides of the dome, the rafters of the latter are halved; these are of the same scantling as the half rafters below, and are spaced 1 ft. $4\frac{1}{2}$ in. apart, excepting that six pairs are placed close together. The roof covering from the sides of the car to the base of the dome is of tinned sheets, and timber $\frac{3}{4}$ in. thick, tongued and grooved, and finished with a slightly projecting nosing, which constitutes the widest part of the car. The roof covering of the top of the dome is also $\frac{3}{4}$ in. thick; it projects about 9 in. beyond the sides of the dome, and is also finished with a nosing, a close boarding running underneath from this nosing to the side of the dome for the whole length of the car. The roof at each end of the car is finished as in Fig. 2058, the domes being extended in width equal to that of the car, and brought forward to overhang the end platforms.

2063.



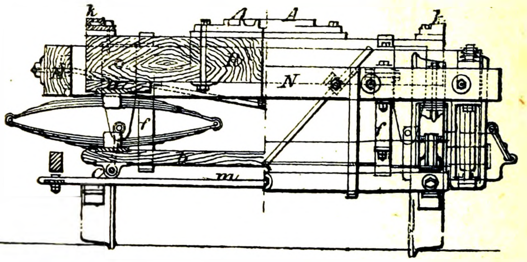
The internal finishing of the vehicle is shown by the longitudinal section at 4, Fig. 2058. From the floor level to a height of 11 in., a plinth of yellow pine *a*, $2\frac{1}{4}$ in. thick, is employed, and above this a lining of ash *b* is used, extending nearly to the level of the sashes; the bottom line of these being marked by a projecting moulding of cherry. The mouldings around the windows are of ash, with intermediate panels of maple, the whole of the lining up to the level of the roof being also of maple, and the base of the dome covered with a moulding of the same wood; maple, indeed, relieved with cherry, forms the chief lining material of the car. The head lining, however, is of painted canvas, stretched on suitable frames, and nailed up in place. The window sashes are glazed, and can be lifted up and down, a spring stop being employed to arrest the sash at any desired point; there being, in addition to the glass, a second sash filled with light louvre boards for use in summer. The seats are arranged transversely on each side of the car, so as to leave a central passage down it for circulation. The frames of the seats are of iron, and swing upon centres, so that the seats can be arranged for passengers to sit in groups of four, *vis-à-vis*, or all in the same direction. The covering of the seats is red or green velvet.

At one end of the car a water-closet W, arranged as in the plan, Fig. 2061, is introduced.

These cars are lighted by gas contained in reservoirs under the frame, three or more lamps being hung from the roof.

The bogie trucks on which the cars of this class are carried are shown to an enlarged scale in Figs. 2062 to 2064; Fig. 2063 being a half side elevation and half longitudinal section; Fig. 2064 a half end elevation and half cross section; and Fig. 2062 a half plan of upper side of framing.

2064.



This truck consists of a main timber frame, 10 ft. long, and 7 ft. $1\frac{3}{4}$ in. wide outside; the side frames being 9 in. deep in the middle by $7\frac{3}{4}$ in. at the ends, and $4\frac{1}{2}$ in. thick; and the end timbers $4\frac{7}{8}$ in. by $6\frac{1}{2}$ in. The side timbers M are 6 ft. $7\frac{1}{4}$ in. apart outside, and the end timbers N are secured into them for their full depth, the under side being flush. Eleven inches within the side frames, inner timbers 3 in. by $5\frac{1}{2}$ in. are stretched from the ends to the centre framing O, which carries the car centre A; this centre framing consisting of two transverse beams $4\frac{3}{8}$ in. by 9 in., which are mortised into the longitudinal timbers M, and are placed $12\frac{1}{4}$ in. apart in the clear; a central beam R, 12 in. by 8 in., which stops short of the side timbers M by $2\frac{1}{4}$ in. on each side, and which is so placed that its upper surface rises above the level of the frame, being placed between the timbers O. On each side of the timbers O are placed two truss rods, 1 in. in diameter, passing through the side frames and secured by nuts, while in the middle they are strained under a saddle plate which passes beneath the central part of the framing, and is bolted to the timbers by two $\frac{3}{4}$-in. bolts; a couple of light straps, $2\frac{1}{4}$ in. wide, also pass over the central transverse beam R, and are bolted to the two outer timbers O. The central beam R is carried by the arrangement of springs S, there being three pairs of these springs on each side of the truck. Each of the springs S is built up of six leaves 3 in. wide and collectively 2 in. thick, the length being 36 in., and the distance between the top and bottom springs in each pair 5 in. at the centre. The clips of the upper springs take their bearings on a cast-iron plate, which is received into the under side of a packing strip *a*, Fig. 2064, 12 in. long, by $12\frac{1}{4}$ in., and 2 in. thick, bolted to the bottom of the central beam; and similarly the clips of the lower spring rest on a second cast-iron plate supported by the beam *b*, 5 ft. $5\frac{1}{2}$ in. by $12\frac{1}{2}$ in. by $2\frac{1}{2}$ in. Underneath this bar and 4 ft. $6\frac{1}{2}$ in. apart are placed two cast-iron brackets *c*, through which passes a bolt $1\frac{1}{2}$ in. in diameter; the length of this bracket is $14\frac{1}{2}$ in., and the bolt *d* projects at each end sufficiently to receive a link *e*, $2\frac{1}{2}$ in. wide and 7 in. long; a pin $1\frac{1}{4}$ in. in diameter passing through the upper end of this link and through a strap slung over the transverse timber in the centre of the truck; these straps being each bolted to the timbers by two $\frac{5}{8}$-in. bolts. Two light wrought-iron arresting straps *f*, bolted to the under side of the frame, are placed to support the swing portion of the frame in case of fracture.

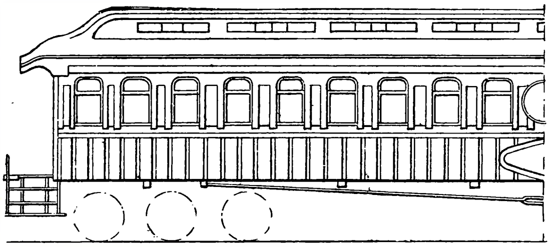
The cast-iron pedestals P, are placed 6 ft. apart from centre to centre. Over the centre of the journal, which is 7 in. long, is a recess in the top of the axle box $2\frac{5}{8}$ in. wide, which forms the bearing for the bent bar B, which carries the rubber side springs S′; these bars are 2 in. thick, and $3\frac{1}{2}$ in. deep in the centre, and the ends are curved upwards as shown, where they pass behind the pedestals to take their bearings. The springs S′ are placed 2 ft. 8 in. apart from centre to centre; they are formed of blocks of solid indiarubber 8 in. in diameter and 7 in. deep, placed in top and bottom sockets *g*, *h*. A flat bar *l*, $3\frac{1}{2}$ in. by $\frac{5}{8}$ in. extends from pedestal to pedestal, the ends being turned up so as to catch on the outer side of each pedestal, to which the bar is bolted; while at a distance of 2 ft. $2\frac{5}{8}$ in. from the centre of each axle, a transverse rod *m* passes across the truck, connecting the bars *l*; the bars *m* are 1 in. in diameter, and are made with a palm at each end. which embraces the flat tie-bar between the pedestals, the connection being made with a bolt as shown.

The side frames are strengthened by the addition of bars 1 in. square, the bottom inner corner of the frame being cut out to receive them; these bars are secured by nuts at the end of the frame, and are placed horizontally for a distance of 6 ft., corresponding to the distance apart of the pedestal casting. At each end of the bolster R, and on the upper side, is bolted a casting *k*; these castings forming bearings for the body of the car. The cast-iron plate A, is that on which the truck turns when running; it is 2 ft. $5\frac{1}{2}$ in. long, and is formed of a disc 17 in. in diameter, with annular channels, and two projecting laps, with a $\frac{7}{8}$-in. hole in each, through which passes a bolt holding the plate upon the bolster; in the centre is a circular hole, and a corresponding opening is in the bolster through which the bolt passes connecting the plate on the carriage, D, Fig. 2058, to the truck.

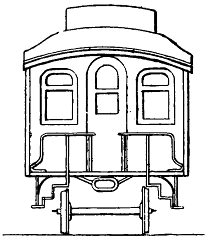
The axle guard is made of $\frac{1}{2}$-in. plates 3 in. wide, and is bolted to the frame timber by two $\frac{3}{4}$-in. bolts at the ends, and two inner bolts of the same diameter passing through cast-iron distance pieces as shown. One side of the lower part of each of these axle guards is turned over to form a bracket, through which passes the rod *n*, and around this rod is coiled a spiral spring, which presses against the break lever L. The brake rigging is clearly shown in the drawings;—Two light plate-iron guards *o* are bolted to the end timbers, and protect the floating bar F; to the latter are bolted the brake blocks and the forked bars P, which are pinned to the levers L, these levers being different for the two ends of the truck, as will be seen in Fig. 2062. The upper end of the lever slides in a wrought-iron guide *r* bolted to the timber, and that of the opposite lever passes through the loop *s*, which is drilled with a series of holes, through either of which a pin can be passed to regulate the position of the lever, both levers being connected by a bar, so that the brake power delivered on one is transmitted to the other end of the truck. The floating brake bar F, with the brake blocks, is suspended to a rectangular link *v*, ¾ in. in diameter, the lower side of which passes through the block attachment, and the upper part through a bracket which is bolted to the under side of the end framing timber.

Fig. 2065 is a half side elevation, and Fig. 2066 an end elevation of a standard sleeping car, fitted with twenty-four double berths; a double berth being almost invariably allotted to each passenger. The construction of the bottom framing of this car, and of the body is similar to the first-class car above described, the internal arrangements and fittings being mainly like those of the Pullman sleeping car, though perhaps not quite so elaborate. This type of car is carried on two six-wheeled bogie trucks; and its principal dimensions are;—

2065.



2066.

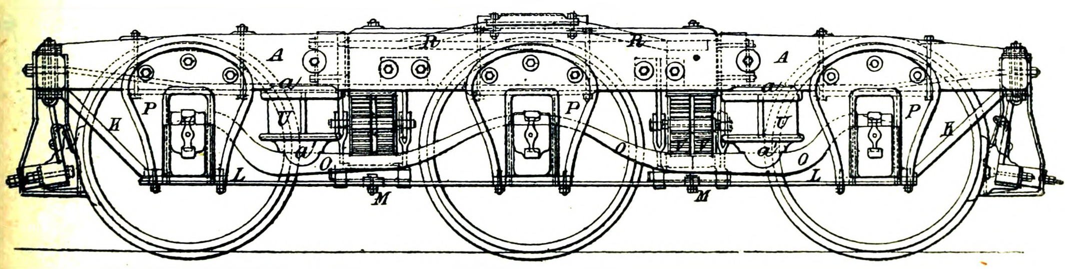


	ft.	in.
Length of bottom frame	58	0
Total length over buffers	64	8
Distance between centres of bogies	44	0
Wheel base of each bogie	9	0
Diameter of wheels	2	9
Width of body inside	10	0
,, over all	10	11
Height inside, at centre	9	9
,, above level of rails, of under side of body	3	6
Total height above level of rails	13	10
Average weight of a car unloaded	25 to 26 tons.	
Weight of six-wheeled bogie truck	4 tons 5¾ cwt.	

Fig. 2067 is a side elevation, Fig. 2068 a longitudinal section, Fig. 2069 a half end elevation and half cross section, Fig. 2070 a longitudinal section through centre of bolster body, and Fig. 2071 half plan of the six-wheeled bogie trucks on which these cars are carried.

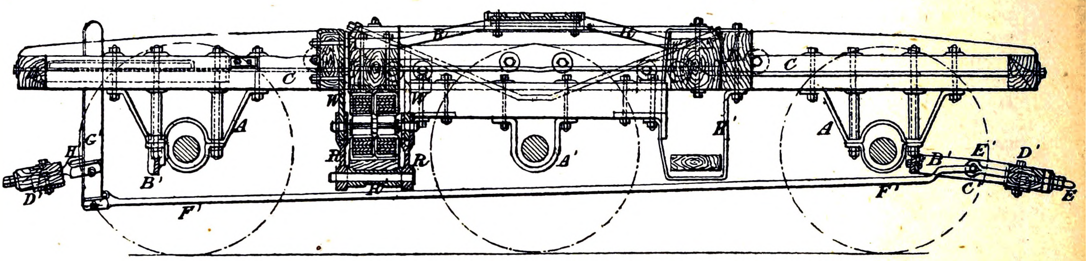
The total length of this truck is 13 ft., and its outside width 7 ft. 1¾ in.; the main side frames are 9¼ in. by 4½ in, and the end timbers 4½ in. by 5½ in. The pedestals P, are of the same pattern as those in the four-wheeled truck, and they are connected at the bottom by a flat horizontal bar L, 3½ in. by ½ in. thick; these bars being tied together at the two points M, by round bars 1 in. in diameter. From the outside pedestals to the end frame, struts K, 1¼ in. in diameter, and with sole plates at each end, complete the bracing of the frame. Iron beams O, 2 in. thick and 3½ in. deep in the widest part, take their bearings on the axle boxes; and between the upper edge of these and the under side of the side frame, are interposed indiarubber block springs U, resting in sockets. The arrangement of bolster frame is as follows;—Transverse timbers D, 3⅛ in. by 9 in. and 4 ft. 10 in. apart in the clear, span the distance between the main side timbers A, in the middle of their length, and parallel to them and 10⅜ in. distant from them, longitudinal timbers C, 3¾ in. by 5½ in.,

2067.

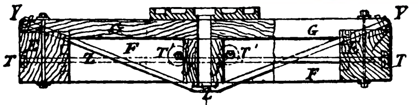


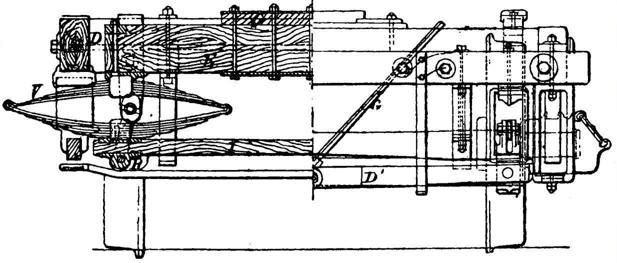
pass from the transverse beam D, to the end timber B. Between D the bolster frame is placed. This consists of two timbers E, $7\frac{3}{4}$ in. by 8 in., and two F, 6 in. by 7 in., connected together to form a rectangular frame, measuring 4 ft. 2 in. by 4 ft. $9\frac{3}{4}$ in. On the top of this are placed the timbers G, 3 in. thick, and in the centre two others, J. The frame is tied in longitudinally by two $\frac{3}{4}$-in. bolts T, and trussed by rods Z, of the same size, taking their centre bearing on plate Z′, and bolted up against the plate Y on the top of the frame. Strengthening bars R are recessed into the top sides of the frame, and are bent to the form shown, as the centre of the bolster frame rises in the centre to receive the cast-iron centre plate Q; the whole being covered with light sheet iron. Two horizontal transverse tie-rods T′ are also introduced. The centre plate Q is $16\frac{7}{8}$ in. in diameter, and corresponds with that for the four-wheeled truck previously described; and it is secured by the bolts which pass through the framing and the plate Z′ already mentioned. The bolster frame is carried upon four pairs of springs V, arranged in couples; these springs being built up of seven plates each. The clips bear upon cast-iron plates at top and bottom, the former being bolted to the timber E and the latter to the beam I; the manner of suspension being as follows;—

2068.



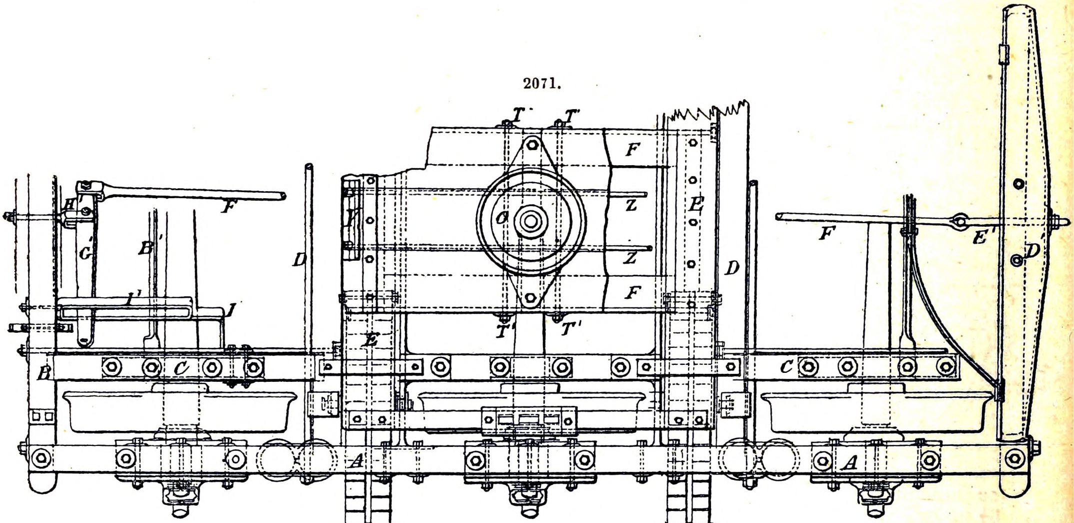
2070.





2069.

2071.

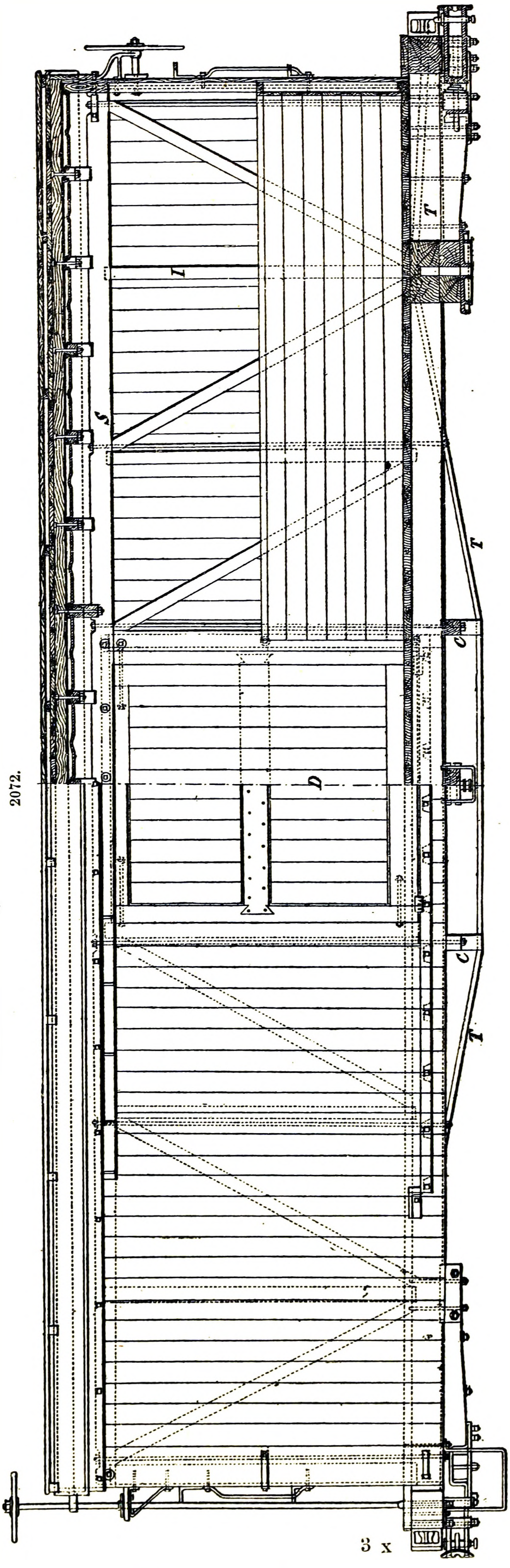


On one side a bracket W passes around the timber D, and is bolted thereto by two ¾-in. bolts, and on the other the bar W′ is bolted to the side timbers A, and stretches between them the whole width of the truck. The links R, 8 in. between centres of pins, are attached respectively to the bracket W and the bar W′, and below to the casting R′, through which a 1½-in. pin passes and retains the whole in position. The under side of the brackets R′ is cut away to allow for clearing the tie M, which is placed close beneath them; the timber I is 7¾ in. by 2½ in. Guard brackets K′ are provided, as well as axle guards A and A′, a bar B′ passing transversely between each outside pair of axle guards; that on the right-hand end of the truck having attached to it in the centre a spring plate C′, which bears against rubbing plates in the floating brake beam D′, and replaces the spiral springs employed in the four-wheeled truck. The eye-bolt E′ passes through the floating beam, which is protected underneath by an iron plate, and to it is attached the brake link F, the forked end of which at the opposite extremity of the truck is connected to the lever G′, attached to the floating beam by the forked bar H′, and moving at its upper end in the guide I′.

A standard box car, or covered goods waggon, of the Pennsylvanian Railway is illustrated in Figs. 2072 to 2074, Fig. 2072 being a half side elevation and half longitudinal section; Fig. 2073 a half cross section and half end elevation; and Fig. 2074 a quarter plan of bottom framing and a quarter sectional plan of body.

The principal dimensions of this waggon are;—

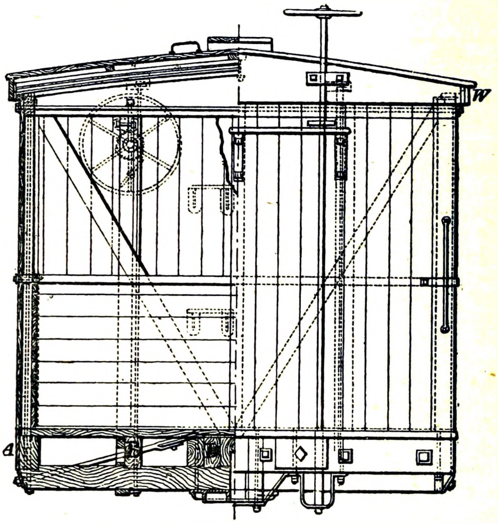
	ft.	in.
Length of bottom frame	29	10¾
" " " between end sills	28	4¾
Length of stringers	28	7¾
" end sills	8	2¾
" platform plank	8	3¼
Width of bottom frame	8	0
Height of under side of frame above level of rails	3	2½
Total height above level of rails	11	3½
Length of body, outside	28	0
" " inside	27	5¼
" running board of roof	28	4½
Width of body, outside	8	1¼
" " inside	7	5¼
Width over all	8	9
Height inside at sides	5	10¼
" " centre	6	8
Width of door	5	6
Height "	6	2⅜
Diameter of wheels	2	9
Wheel base of each bogie	4	10
Distance apart of centres of bogies	20	4¾
	tons.	cwt.
Weight of car, about	8	19
" each bogie	4	1¼
Capacity.—General merchandise	7	2¾
Flour	9	13
Grain	9 to 10¼ tons.	



2072.

The bottom frame of this waggon consists of six longitudinal sills, the outer ones A 4 in. by 8 in., and the inner ones B 3 in. by 8 in.; the end sills being 8 in. by 9 in. Cross timbers trussed in the ordinary way are placed over the trucks, similar to the frame of the first-class carriage previously described, and two intermediate sills C, 3½ in. by 6 in., are placed under the longitudinals; additional framing timbers being introduced between the end sills and the transverse framing over the trucks, and to this frame the coupling and central buffer are attached. Two truss rods T run from end to end of the frame, passing through the end sills over the cross beams above the trucks, and beneath blocks attached to the under side of the intermediate sills C.

2073.

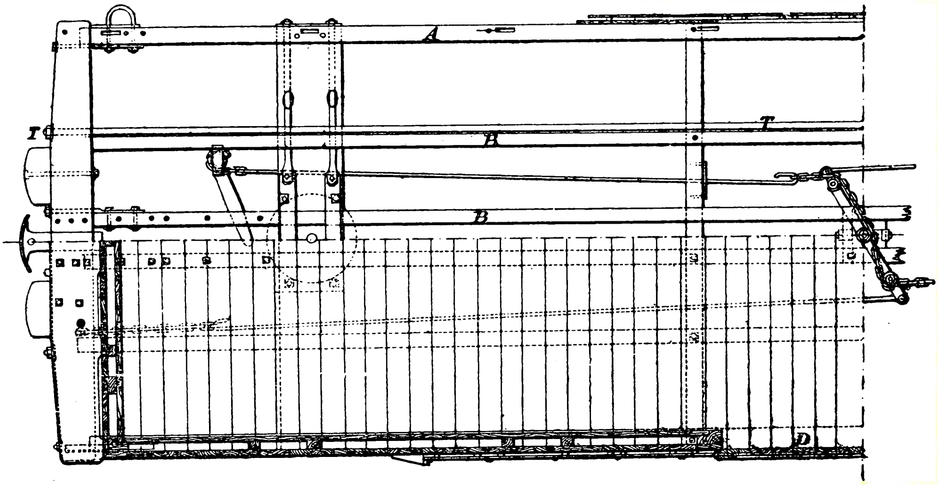


The body is framed at the four corners by posts 3½ in. by 4½ in., 8 ft. apart and 6 ft. 3 in. in length, and at short intervals by intermediates I, 2½ in. by 3 in.; diagonal braces are placed between these posts, and are framed at the bottom into the longitudinal timbers A, and at the top into the upper sill S, these braces being of the same size as the posts, namely, 2½ in. by 3 in. At the side of each vertical post I a rod ⅝ in. in diameter passes from the roof sill S to the longitudinal timbers A, and horizontal tie-rods are also employed to tie these posts together at intervals under the roof. On the top of the posts I a sill S, 2¼ in. by 5 in., is framed, and to this the side planking is secured.

The flooring of the car is of 1¾-in. planking, tongued and grooved, and laid over the frame beyond the body at each end. For a height of 2 ft. 10¼ in. above the floor line, the sides of the car are made double, of ¾-in. planking, tongued and grooved, and placed one thickness outside and one inside the posts; the outer planking on the sides of the body falling outside the main longitudinal sills. At the height of 2 ft. 10¼ in. above the floor a moulding runs round the inside of the body of the car; and above this level the body is formed with a single boarding, that is, the planking outside the posts only is extended to the roof.

The main roof timbers or carlines are framed into the roof sill S, one at each end and one in the middle. At intervals of about 1 ft. 9 in., light rafters, 2½ in. square, are framed, and these carry two purlins and a ridge piece, upon which the roof planking, ⅞ in. thick, is laid. A weather strip W, 4½ in. deep, runs along outside the roof sill S; and a head lining is also introduced.

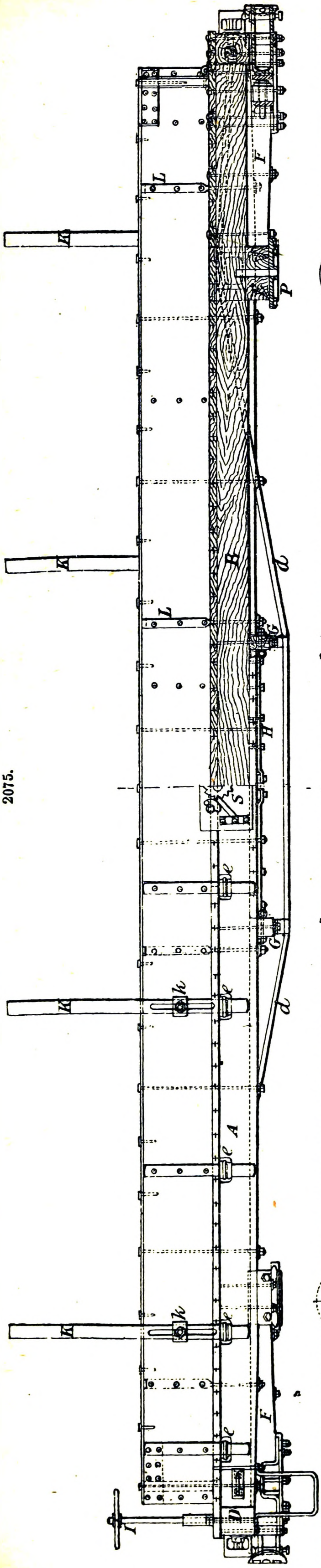
2074.



In each side of the body is formed an opening, 5 ft. 4 in. long and 6 ft. in height, these openings being closed by sliding doors D, ⅞ in. thick, running in guides which are bolted to the longitudinal timbers A, and to the roof sills S.

Of the style of bogie truck, called a diamond truck, and which is generally adopted for all kinds of freight cars, Fig. 2078 is a half side elevation and half longitudinal section; Fig. 2079 a half end elevation and half cross section; and Fig. 2080 a half plan partly in section.

The wheels W are of chilled cast-iron, 2 ft. 9 in. in diameter, and are mounted on wrought-iron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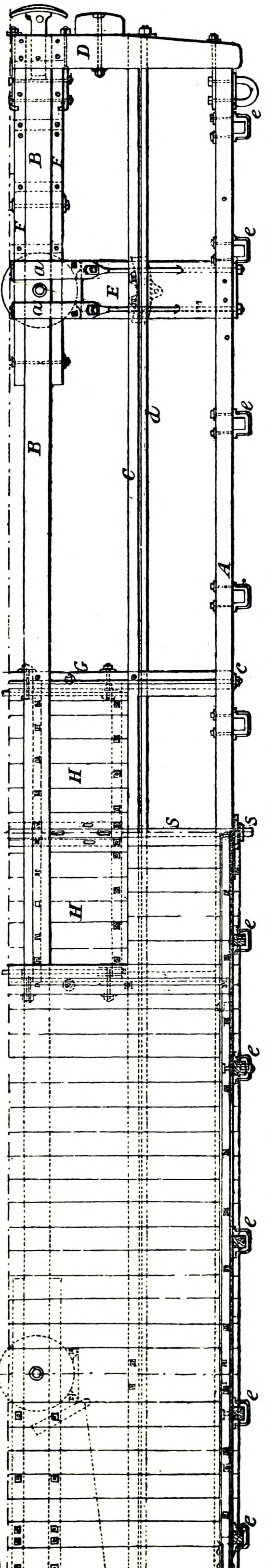
2075.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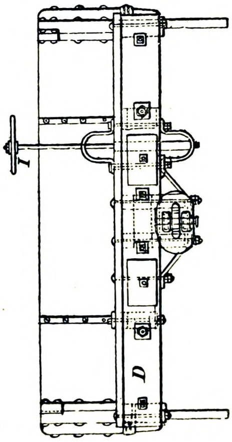
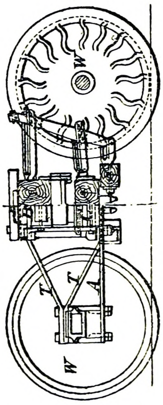
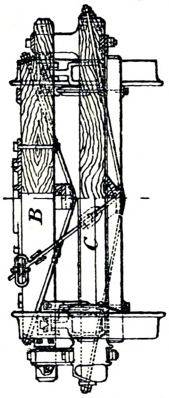
2076.



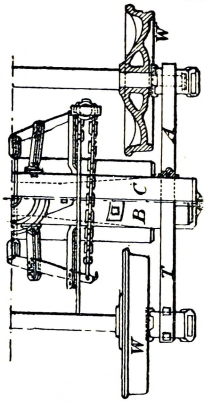
2077.



2078.



2079.

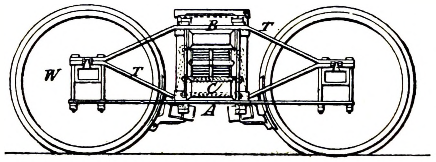


2080.

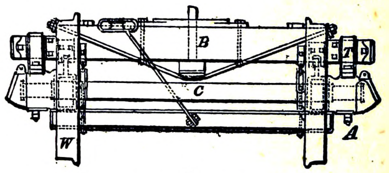
3 x 2

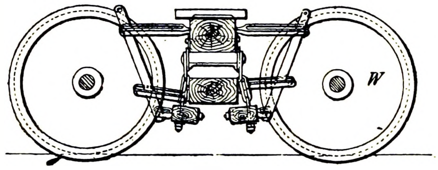
axles $4\frac{1}{8}$ in. in diameter; the bearings in the wheel seats being 4 in. in diameter and $6\frac{1}{4}$ in. long, and the journals 4 in. in diameter and 7 in. long. The wheels are placed 4 ft. 10 in. apart, and are connected by outside framing, which consists of a horizontal bar A passing between the axle boxes and fitting into recesses on their lower sides. On the top of the axle boxes, and fastened by through bolts, are the ends of plates T, 1 in. thick, which diverge towards the middle of the truck until they are 16 in. apart, when they again become horizontal, and rest, the lower member on the bar A, and the upper on the end of the bolster B; through bolts which pass inside cast-iron distance pieces securing the structure together. The upper bolster B consists of one timber 10 in. by 8 in., reduced at the ends for a distance of 10 in. to allow the upper bar of the side frame T to pass over it; this beam B is trussed as shown in the cross section, Fig. 2079, the truss rods passing into the centre under a wooden packing and cast-iron saddle. The lower bolster C is 6 in. by 10 in., and 7 ft. 3 in. long, and is trussed similarly to the upper one, but with only one end rod. To both bolsters the brake rigging is attached, the floating beams being hung to the upper one. The springs are ordinary leaf springs 2 ft. 9 in. long, and are built up of seven plates $\frac{3}{8}$ in. thick, and tapered off to $\frac{3}{16}$ in. at the ends; the plates are parallel throughout, and 3 in. wide, the overlap of each leaf, except the top one, is $2\frac{1}{4}$ in., that of the latter at each end being $1\frac{1}{4}$ in.

208 .

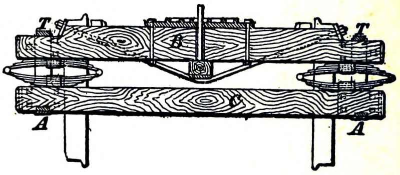


2080*d*.



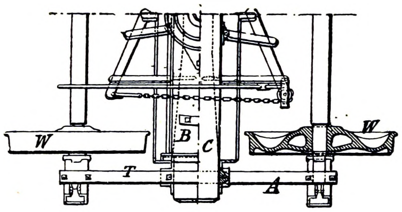


2080*b*.

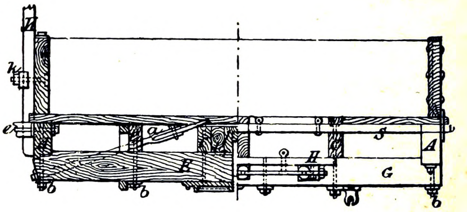


2080*e*.

2080*c*.



2081.



A standard drop-bottom gondola car, or open goods waggon of the Pennsylvania Railway, is shown in Figs. 2075, 2076, and 2081. Fig. 2075 is a half side elevation and half longitudinal section; Fig. 2077 an end elevation; Fig. 2081 a cross section, half through the upper turning plates, and half through the centre bottom door; and Fig. 2076 a half plan of car and half plan of bottom framing.

The principal dimensions of this car are;—

	ft.	in.
Length of bottom frame	31	1
„ inside end sills	32	0
„ over all	34	3
„ of sides of body	31	$7\frac{1}{2}$
„ of body, outside	31	$1\frac{1}{2}$
„ „ inside	30	$9\frac{1}{2}$
Depth „ outside	1	$7\frac{3}{4}$
„ „ inside	1	6
Width „ „	7	$6\frac{1}{2}$
„ „ outside	8	0
„ over all	8	$6\frac{3}{4}$
Bottom door, length	5	6
„ width	4	0
Distance apart of centres of bogie trucks	22	6
Weight of car, empty	9 to $9\frac{1}{2}$ tons.	
„ each bogie	4 tons $1\frac{1}{4}$ cwt.	
Maximum load	10 to 12 tons.	

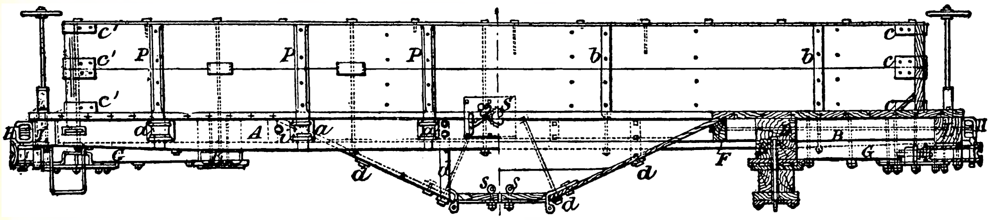
The bottom frame consists of five longitudinal timbers, the two outer ones A being 4 in. by 10 in., the middle timber B 6 in. by 9 in., and the intermediate pair C 3 in. by 9 in.; these are connected, by end sills D, 8 ft. $2\frac{3}{4}$ in. long, and 8 in. by 9 in. in the middle, reduced towards the ends as shown in the plan, Fig. 2076. At 5 ft. $3\frac{1}{2}$ in. from the outer face of the sills is the cross framing E, carrying the upper turning plates P; this consists of a sill 6 in. by 14 in., framed under the longitudinals, and bolted to them, side pieces F, $3\frac{1}{4}$ in. by 8 in., being bolted on each side of the central longitudinal B, and extending for a distance of 2 ft. from the centre pin of the truck to the end of the frame, and outside these side pieces are two blocks *f*, 4 in. by 14 in. Passing over the central longitudinal side pieces and blocks are two straps *a*, 10 in. apart from centre to centre, and $3\frac{1}{2}$ in. wide, bolted down as shown, the ends of these straps being attached to truss rods, which pass through holes made in the cross sill E, and are secured by nuts at the outer ends; the cross sill E being also bolted to the longitudinals C by $\frac{5}{8}$-in. bolts *b*. At a distance of 7 ft. 11 in. from the cross sill E are two other transverse timbers G, 4 in. by 6 in., bolted to the main sills, and passing underneath them; and to these timbers are attached the drop doors H, in the bottom of the car. A tie-rod *c*, $\frac{3}{4}$ in. in diameter, passes transversely through the frame over the cross sills G, and two longitudinal tie-rods *d*, 1 in. in diameter, extend from end to end of the frame; these latter rods *d*, which are placed just outside each of the intermediate longitudinal timbers C, are bolted to the end sills D, passing through them about the middle of their depth, then over blocks resting on the cross timbers E, and thence underneath the frame, where they bear in cast-iron sockets bolted to the middle cross-sills G. The brake wheel I is placed at the end of the frame.

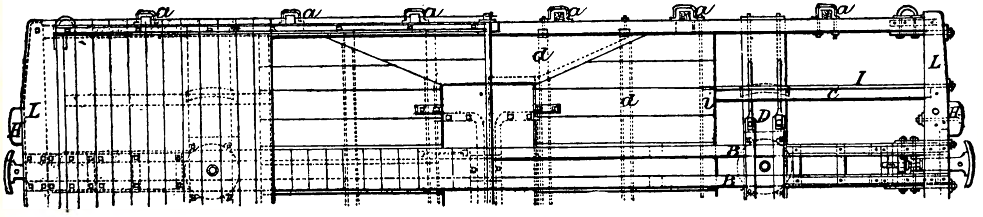
The bogie trucks are of the type already described, in connection with the covered goods waggon, Figs. 2072 and following; and are shown rather more in detail in Figs. 2080*a* to 2080*e*.

To the face of the outer longitudinal timbers A, at intervals varying from 2 ft. 7 in. to 3 ft. 7 in. are secured sockets *e*, by means of staple bolts passing round the middle of the socket, and held by nuts on the inner side of the sill; vertical posts K, 3 in. by $3\frac{1}{4}$ in., are placed in these sockets, some of them extending only to the top of the sides of the car, and others about 3 ft. longer, the former being fastened to the sides by three bolts, as shown, and the latter slotted, so that their heights can be adjusted, and they are fixed by a bolt *k* passing through the slot, and a nut and washer plate. The sides of the car, $2\frac{3}{4}$ in. thick, besides being connected with the frame by means of the side posts K, are secured by straps L, 2 in. wide and $\frac{5}{8}$-in. thick on the inner face of the side, the lower part of this strap being formed with a $\frac{3}{4}$-in. bolt which passes through the frame, and the upper end turned over and recessed into the top of the side. Eight bolts, $\frac{3}{4}$ in. in diameter, also pass through each side and frame. The corners of the body are protected by angle plates, and the top by a flat plate secured by bolts. The floor of the car is $1\frac{3}{4}$ in. thick; it is tongued and grooved, and is laid on the main sills of the frame, projecting slightly beyond the outer timbers.

The drop bottom is placed in the middle of the car, and forms a kind of well, 8 in. lower than the floor of the car, and is closed by doors which abut against the under side of the longitudinals C, the central longitudinal B running through the well; the ends of the well being formed of timbers 4 in. thick, tenoned into the longitudinals B C. The planking of the bottom door is 2 in. thick, and the hinges, which are bolted to the transverse sills of the frame, extend to the ends of the doors; the doors are raised and lowered by means of the shaft S, running across the car, and carrying a ratchet wheel at one end.

2082.





2084.

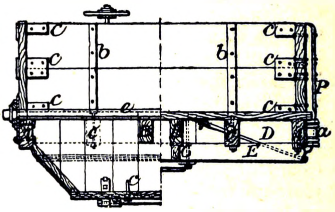
In Figs. 2082 to 2084 is shown the standard hopper-bottom gondola car of the Pennsylvania Railway, this being the type of waggon which is generally employed for the conveyance of coal and other similar material which can readily and conveniently be discharged from the bottom of the car. Fig. 2082 is a half side elevation and half longitudinal section; Fig. 2083 a cross section, half through the cross framing over truck, and half through the centre of hopper bottom; and Fig. 2084 a half plan, showing part of the bottom framing.

The principal dimensions of this car are;—

		ft.	in.
Length of bottom frame		26	0
„ inside end sills		24	8
„ over all		27	2
„ of body outside		24	0
„ „ inside		23	6½
Depth „ inside		2	5
Width „ outside		8	0
„ „ inside		7	6½
„ over all		8	9
Length of hopper bottom, at top		12	0
„ „ „ at bottom		2	7½
Width „ „ „		4	7
Length of door in hopper bottom		2	10
Width „ „ „		5	0
Distance apart of centres of bogie trucks		15	6
Weight, unloaded, about	9 tons.		
„ of each bogie truck	4 „ 1¼ cwt.		
Average load	16 „		

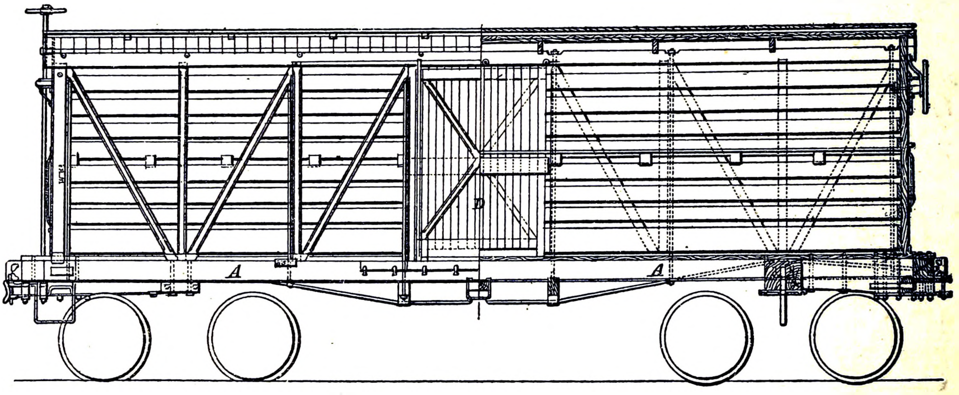
The bottom framing of this car consists of six longitudinal timbers, the outer and middle pairs of which A, B are each 4 in. by 10 in., the intermediate pair C being 3½ in. by 8 in., and the end timbers L being 9 in. deep and 8 in. wide in the middle, and tapered as shown. The cross framing over the truck consists of a timber D, 14 in. by 8 in. in the centre, and underneath a second timber E, 14 in. by 6 in., extending between the outer frames; the whole being trussed similar to the drop-bottom car above described. A cross beam F, 4 in. by 8 in., is also introduced immediately below the commencement of the inclined portion of the floor. The underframes at the ends of the car, to which are attached the central buffer, which is also the draw-bar, consist of two timbers G, placed under the central pair of main longitudinal timbers B, in the same manner as in the drop-bottom car above described; and two bumpers H, of cast iron, 2 ft. 6 in. apart, are placed on each end of the end sills L. Two rods I, 1 in. in diameter, are introduced at each end, extending from the buffer beam to the cross timber at the commencement of the incline, and transverse rods *i* are also introduced.

2083.



Along the outside longitudinal timbers A, cast-iron sockets *a* are bolted at intervals of 4 ft. and 3 ft. 6 in., to carry posts P, which extend to the top of the car, and to which the side timbers are bolted in the manner shown, these side and end timbers being 2¾ in. thick, and two of them form the depth of the body. The sides and ends of the body are strengthened and held together on the inside by iron straps *b*, 2 in. wide by ½ in. thick, running from the floor vertically to the top of the body, there being four of these straps on each side and two at each end of the car, each fastened to the timbers by four ¾-in. bolts placed 6 in. apart. Besides these straps *b*, there are three inner and outer straps *c*, *c'* at each angle of the car, which are also bolted through as shown; and the top of the body is protected by a flat bar running all round, and fastened to the timbers by coach screws.

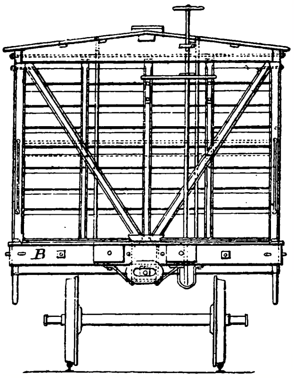
2085.



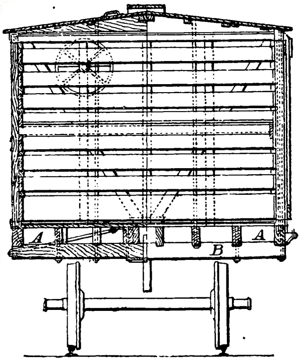
In the centre of its length, the bottom of the car is placed 2 ft. 1 in. below the main floor level, and this hopper is closed by two doors, the floor of the car being connected with these doors by an incline on all four sides, the length of the opening on the floor level being 12 ft. and the width 7 ft. 6½ in. The inclined portion of the bottom is of 1¾-in. timbers, held together by two straps, 3 in. by ½ in., running along it on each side, in the middle of the length of the incline, and at the bottom, as shown. At the bottom of each portion are bolted the hinges by which the doors are attached, these doors being each of them 1 ft. 5 in. wide, and when closed they are held in a horizontal position by means of chains attached to the staples *s*, these chains passing round a shaft S′ running across the car near the floor line, and having at one end a toothed wheel, gearing into another wheel, which is moved by a lever from the outside of the car.

A cattle car of the Pennsylvania Railway, constructed to carry two tiers of sheep or swine, is shown in Figs. 2085 to 2088. Fig. 2085 is a half side elevation and half longitudinal section; Fig. 2086 an end elevation; Fig. 2087 a cross section; and Fig. 2088 a half plan of bottom framing, a quarter plan of roof timbers, and a quarter plan of interior of car.

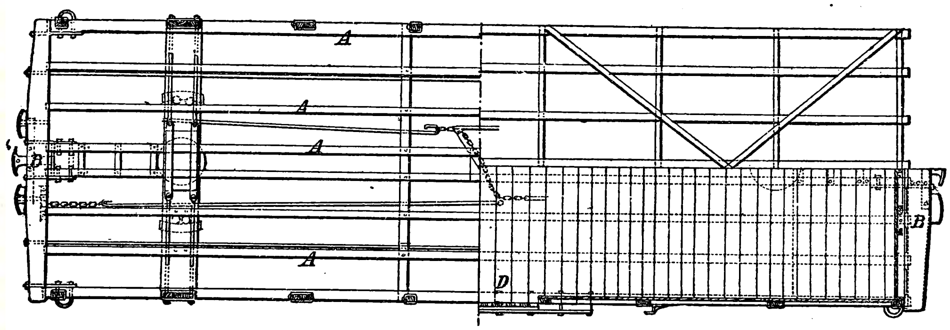
2086.



2087.



2088.



The principal dimensions or this car are as follows :—

	ft.	in.
Length over all	31	0$\frac{3}{4}$
„ of bottom frame	29	10$\frac{3}{4}$
„ of body	28	0
Width over all	9	6
„ of bottom frame	9	2$\frac{3}{4}$
„ of body	9	0
Total height above level of rails	11	10$\frac{5}{8}$
Height of body at sides	6	8
„ to under side of middle floor	3	2
Distance between centres of bogie trucks	19	7$\frac{3}{4}$
„ from end of frame to centre of bogie truck	5	1$\frac{1}{2}$
Wheel base of each bogie	4	10

The bottom frame of this car consists of eight longitudinal timbers A, arranged as shown in the plan, and connected at their ends to the cross sill B. The dimensions of these timbers, together with the system of bracing adopted, as also the cross frames over the trucks for carrying the upper turning plates, are all very similar to, or identical with, those already described for freight cars. The sides and ends of this car consist of a trussed framing with open boarding, having a door D in the centre of the length of each side; and the upper floor is carried on cross timbers supported in cast-iron brackets which are fixed to the side posts.

The weight of this car is about 8½ tons, and its load about 8 tons when carrying pigs, or 7½ tons when loaded with sheep; when constructed with a single floor the load is, cattle 7½ tons, pigs 5½ tons, and sheep about 4 tons.

Figs. 2089 to 2092 are of a tank car which is used for the conveyance of petroleum in bulk; the external appearance of this tank being similar to an ordinary cylindrical boiler. Fig. 2089 is a half side elevation and half longitudinal section; Fig. 2090 an end elevation; Fig. 2091 a cross section; and Fig. 2092 a half plan of tank and half plan of bottom framing.

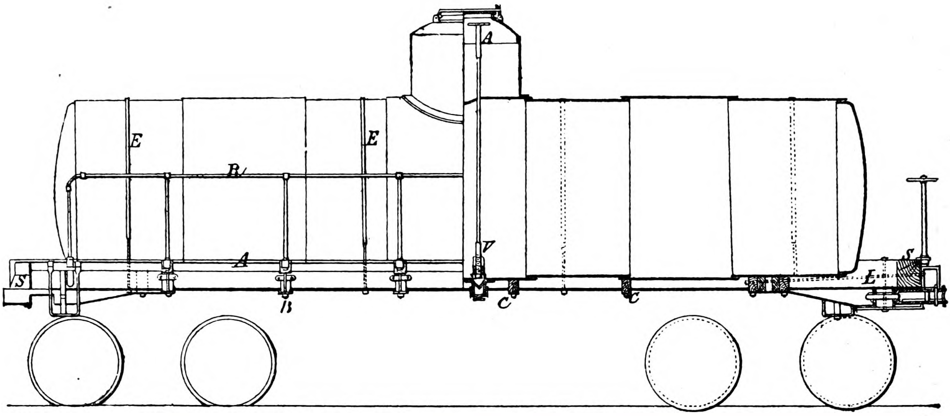
The oil is pumped into the tank through the dome D, and discharged through an opening in the bottom of the tank; the said opening being closed by a valve V, which is placed in a suitable seating, and is operated by means of the rod A.

The principal dimensions of this car are;—

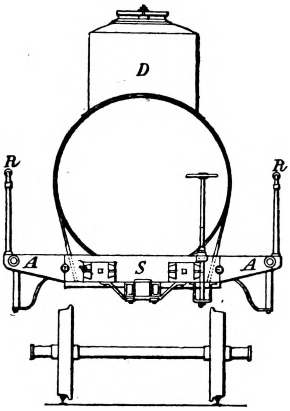
	ft.	in.
Length of bottom frame	28	10
„ „ „ inside end sills	27	3
„ of end sills	8	7
„ over all	29	10
Width over longitudinals B	4	10
Height of handrail above running board	2	8
Width of cast-iron brackets	0	4
Length „	2	3
Depth „ „	0	$10\frac{1}{2}$
Diameter of tank	5	$4\frac{1}{2}$
Length „	25	3
Diameter of dome	3	3
Height from bottom of tank to top of dome	8	1
Total height above level of rails	12	6
Distance apart of centres of bogie trucks	19	3

The bottom framing of this car consists of two longitudinal timbers L which are connected by the end sills S, and are further strengthened by the cross timbers C and tie-rods T. To the outer sides of the longitudinals L are bolted the cast-iron brackets B, which support the platform P surrounding the tank and also carry the handrail R, the outer ends of the brackets B being supported by the bar or tie-rod A, which is bolted through the end sills S. The tank is connected to the bottom frame by means of wrought-iron straps D which pass round it; the ends of the said straps being formed as screws, and passing through the longitudinal timbers L, are secured by nuts and washers.

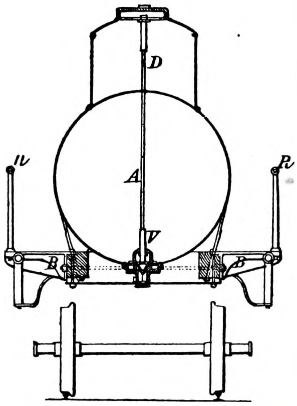
2089.



2090.



2091.



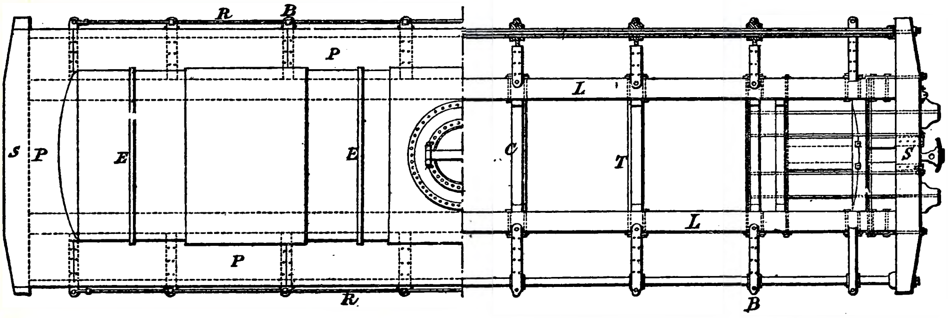
The capacity of the tank, not including the dome, is about 3570 gallons.

Fig. 2093 is a half side elevation and half longitudinal section; Fig. 2094 a half plan of platform and half plan of bottom framing; Fig. 2095 a plan of bogie car; Fig. 2096 a half side elevation and half longitudinal section of ditto; and Fig. 2097 is a cross section, half through the main truck T, and half through one of the trucks T′ of a sixteen-wheel gun truck of the Pennsylvania Railway. The principal dimensions of this truck are as follows;—

	ft.	in.
Length of bottom frame..	31	10
„ inside end sills	30	2
„ over all	33	0
„ of end sills	9	0
Distance between centres of bogies T	17	0
Wheel base of each bogie T	11	3
Distance between centres of bogies T′	7	2
Wheel base of each bogie T′	4	1
Total wheel base	28	3

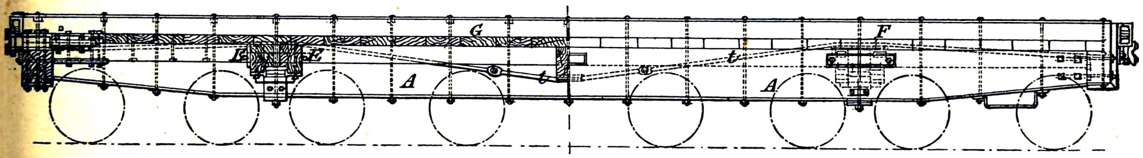
The bottom frame of this truck consists of two outside timbers A, each 17 in. deep by 6 in. wide, the depth being reduced to about 12 in. at the ends; four central timbers B arranged in pairs, each 6 in. by 5 in.; and two intermediate timbers C, each 6 in. by 4 in.; the cross framing consisting of a central timber D, 8 in. by 10 in., and over the centre of each bogie truck two timbers E, each 5 in. by 10 in., and placed 10 in. apart, the frame being strengthened at these parts by the bracing shown in Fig. 2097; and the whole frame is further strengthened and bound together by the longitudinal trussing *t*, and cross tie-rods *t*′. The frame is laid over with 3-in. close planking, and on top of this are two side strips F, 6 in. by 6 in., and two centre blocks G, 6 in. by 12 in.

2092.

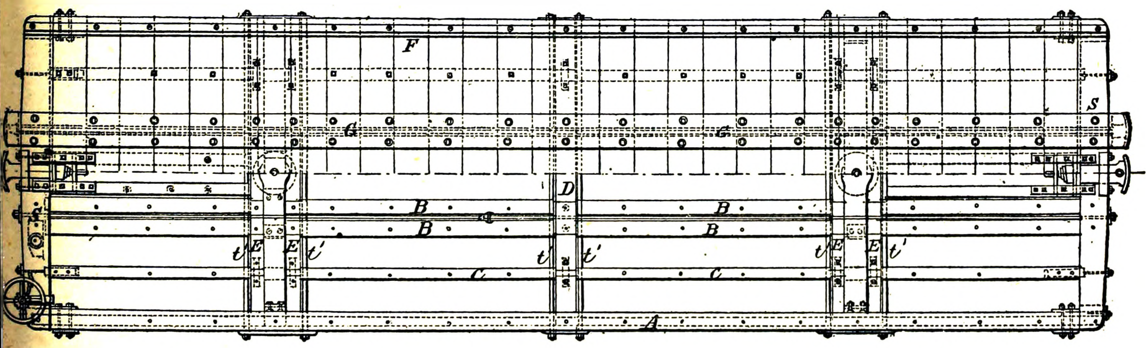


This truck is carried on two eight-wheeled bogies, Figs. 2995 to 2097, each composed of two of the four-wheeled waggon trucks previously described, Figs. 2080*a* to 2080*e*; these two trucks each bear on the ends of a compensating frame, which is formed of two side plates H, placed 3 ft. 8 in. apart, and connected by the two horizontal end plates K, and central plate T; the latter forming the point of connection between the bogie and the underframe of the truck.

2093.



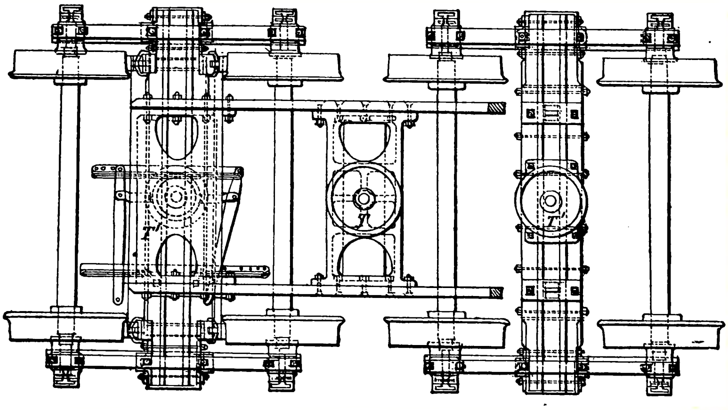
2094.



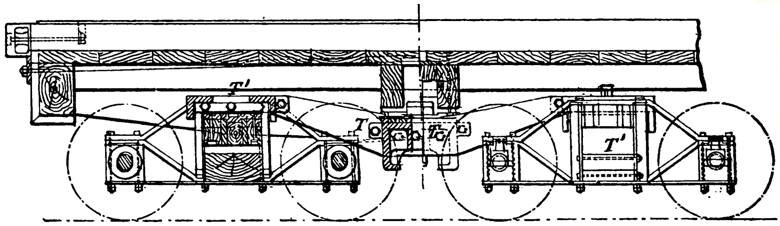
In Figs. 2098 to 2100 is shown a four-wheel coal-truck which is used on the Pennsylvania Railway;

this truck is of very small dimensions compared with the other freight cars, and is one of the few types of rolling stock carried on rigid wheels, the wheels being fastened to a spring beam, instead of being connected to the body of the truck by springs in the usual way. Fig. 2098 is a half side elevation and half longitudinal section; Fig. 2099 a half end elevation and half cross section; and Fig. 2100 a plan, half of the interior, and half of the bottom framing.

2095.



2096.

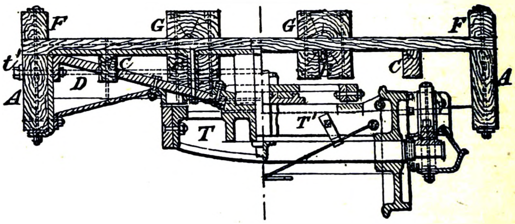


The principal dimensions of this waggon are;—

	ft.	in.
Length of bottom frame	12	0
„ over all	13	0
„ of body outside	11	0
„ „ inside	10	4
Width „ outside	6	6¾
„ „ inside	5	10¾
„ of drop bottom	3	7
Depth of body outside	3	6
„ inside at centre	4	10
„ „ sides and ends	2	6
Diameter of wheels..	2	9
Wheel base	5	0
Weight of car empty, about .. .. .. 4 tons.		

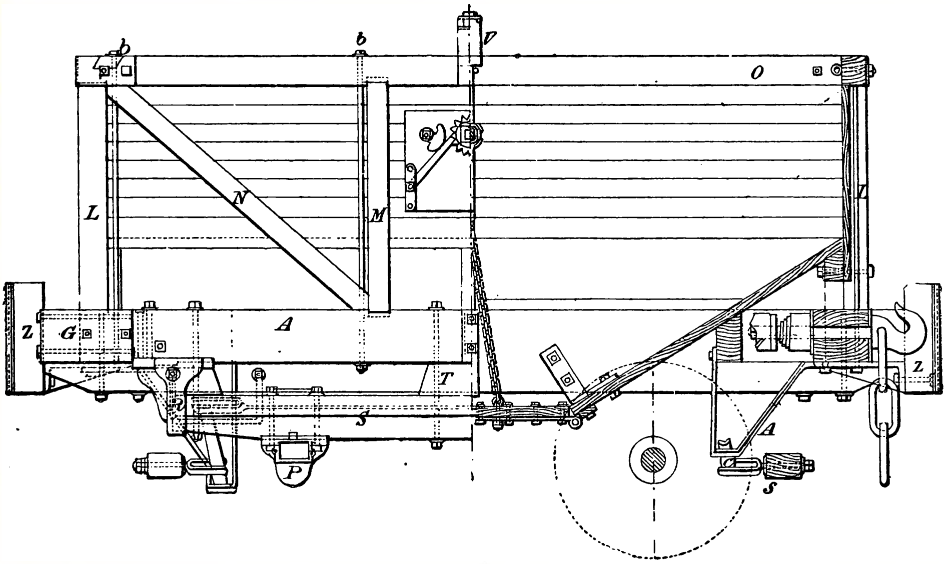
The bottom frame of this waggon consists of two outer longitudinals A, 4 in. by 9 in., and end cross sills B, 9 in. by 9 in. Between the longitudinals A, and 3 ft. 7 in. apart, are two other beams C, 3½ in. by 1 ft. 2 in. deep, the ends of which are cut away, so that the main transverse sills rest upon and are bolted to them; the rest of the cross framing consisting of a timber D, 4 in. by 8¾ in., stretched between the two inner longitudinal beams, and placed 12 in. from the end transverse sills, short longitudinal pieces E connecting these, as shown in the plan; other short lengths also connect the outer and inner longitudinal sills, and to the end transverse sills B timbers F, 4 in. by 9 in., are bolted; these latter, however, stop short of the centre to allow room for the draw-hooks; the angles being covered with iron plates G, as shown. The bolts connecting and strengthening the structure consist principally of two rods H, secured to the end transverse sills, and cross bolts K between the outer and inner longitudinals.

2097.



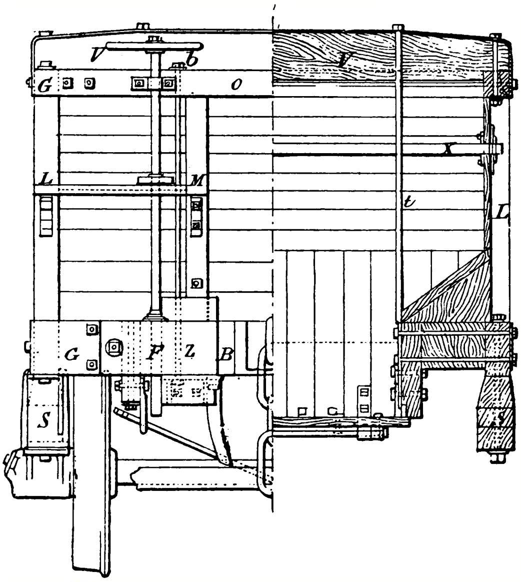
The axles of the wheels run in boxes fixed in pedestals P, which are attached to long spring beams S, placed on each side of the car. The length of the spring beam S is 8 ft. 4½ in.; it is composed of two timbers, the lower one 4 in. by 6 in., and the upper one 3¼ by 6 in., the depth of the lower timber being somewhat reduced towards the ends to give additional elasticity. The extremities of the beam rest in cast-iron sockets R, bolted to the frame of the car, in which sockets they are free to move; and at the centre a block T, 18 in. long, 6 in. wide at the bottom and 4 in. at the top, and 5½ in. deep, is interposed between the beam and the under side of the main timbers A, two through bolts fastening the whole together. By this arrangement the use of springs is avoided, and at the same time sufficient elasticity obtained for the car.

2098.



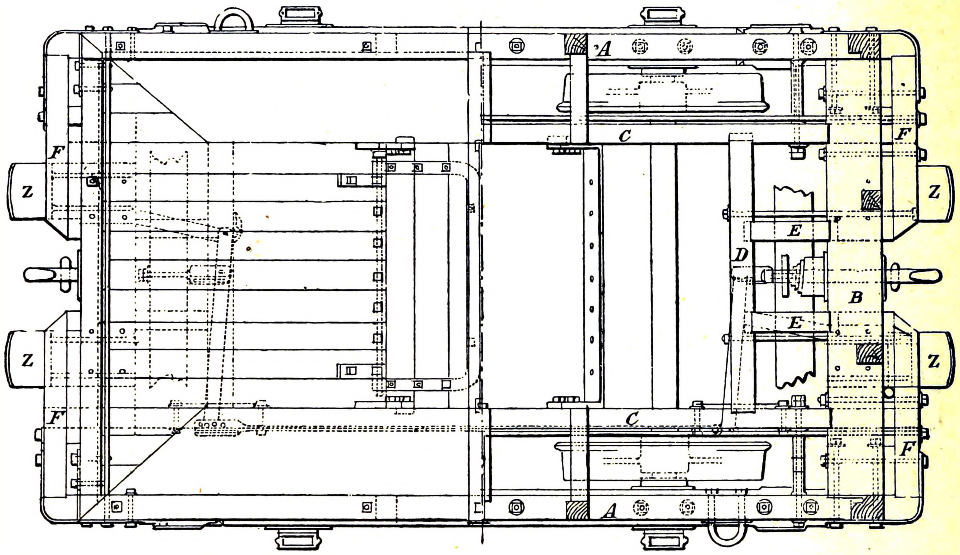
The body of the car is framed on to four corner posts L, 4 in. by 5 in., and four intermediate ones M, 3 in. by 3½ in., raking struts N, of the same dimensions, extending from the foot of each intermediate M to the top of the angle posts L, and a rail O, 4 in. by 4½ in., running round the top of the body. On each side four bolts *b*, 1 in. in diameter, pass from the top rail O through the outer longitudinal sills A, and are bolted to them. The planking of the sides of the body is 1 in. thick, and that of the bottom 1¾ in. At a distance of 2 ft. 6 in. from the top of the body, the car is sloped inward, so as to leave a clear space in the middle of the bottom of the car of 3 ft. 7 in. by 2 ft. 8 in., the method of framing this lower part of the body being clearly shown in the figures. In the centre

2099.



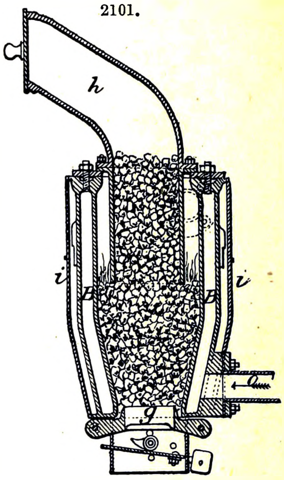
of the length of the car a beam V, 4 in. by 6 in., extends across it, the top of the beam protected by an iron plate. From the beam V pass down two rods *t*, which are bolted to the side of the hopper in the body; and close to the drop doors are two straps, 3 in. by $\frac{1}{2}$ in., which are bolted at their ends to the inner longitudinals, and along their length to the hopper bottom. The doors, which are hung in the usual manner, are suspended by $\frac{7}{16}$-in. chains to a bar X, running across the car, and actuated by a pawl and ratchet placed outside. Two bumpers Z, $18\frac{1}{2}$ in. deep and $5\frac{1}{4}$ in. wide, are placed on each transverse sill.

2100.

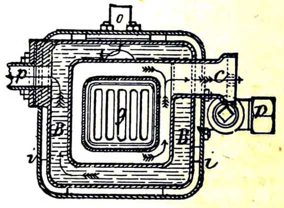


Heating Apparatus.—A heating apparatus, called the Thermosiphon, which has been extensively adopted by the Eastern Railway of France, and which has given perfect satisfaction in its working, is shown in detail in Figs. 2101 to 2106, and as fixed to the carriages in Figs. 1959 to 1961. This apparatus consists of a small cast-iron boiler B, which is fixed on one side of the carriage outside the frame, and is connected to an arrangement of pipes and heaters which warm the carriage. This boiler has an internal fire, the bottom of the fireplace being closed by a hinged firegrate *g*, and the top by a cover fitted with a hopper *h* for the fuel. The chimney *c* is led off from the boiler obliquely, as shown in Fig. 1959, and traverses the body of the carriage between two of the compartments, as shown in the plan, Fig. 1961. The boiler is coated with felt, which is protected by a sheet-iron casing *i*. The water, heated to about 212° F., passes off from near the top of the boiler to two galvanized iron branch pipes *p p*, Fig. 2103, which distribute it to the heaters H at the bottom of the carriage, the pipes *p p'* being made with S bends to give the necessary flexibility, and to allow of expansion and contraction. The heaters or "chauffrettes" H are of cast iron, and are recessed into the floor of the carriage, midway between the seats, as in Figs. 1959 and 1961, page 992, the details of their construction being shown in Figs. 2103 to 2105. These "chauffrettes" extend the full width of the body, the hot water from the boiler entering them at one end *h* and escaping at the other into the return line of pipes *o*, the connections of which are shown in Fig. 2103. The return pipes communicate with the bottom of the boiler, as shown in Fig. 2101, the pipes from the two ends of the carriage uniting into a single branch O. To ensure the "chauffrettes" being cleared of air when the apparatus is filled with water, each has connected to its side a small pipe *b*, which is carried up under the adjoining seat, Fig. 2105, and is then bent over and carried down through the floor of the carriage, its ends being enlarged so as to prevent the pipe from forming a syphon. To accommodate the expansion of the water which takes place when it is heated, there is provided under one of the seats of the central compartment a small tank T, Fig. 2106, which communicates with the line of pipes, the position of the tank being shown in Fig. 1959, page 992. The excess of water caused by the expansion rises up into this tank, and the latter being open to the atmosphere, through the pipe *t*, it is impossible for any excess of pressure to occur in the boiler or system of pipes. To ensure the equal distribution of the heat, the boiler is placed near the centre of the carriage. One of the pipes *p* is

2101.

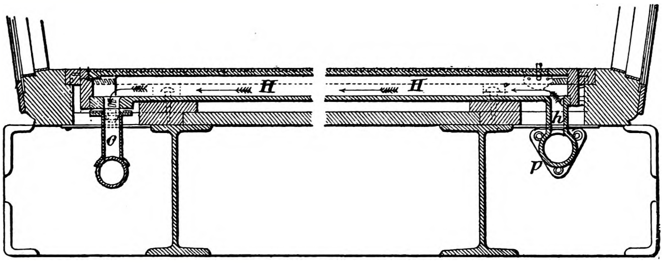


2102.



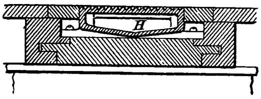
furnished at the end of the carriage with a funnel through which the boiler and pipes can be filled, a three-way cock being provided, and so arranged that, when the filling is completed, any water remaining in the funnel can be run out, so as to prevent trouble from freezing. With this apparatus a temperature of about 18° above the external temperature can be maintained, that is, a temperature of from 46° to 50° F., with the thermometer in the open air standing at freezing point; the arrangement also maintains a temperature of from 122° to 140° F. under the feet. The fire of the heating apparatus can be attended to without opening the carriage door. The cost for fuel for warming a third-class carriage, such as Figs. 1959 to 1961, page 992, is stated to average only one halfpenny an hour.

2103.

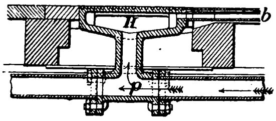


The apparatus designed by M. Regray for heating foot-warmers, and which is employed at the principal stations on the Eastern Railway of France, is shown in Fig. 2107. The foot-warmers are heated by immersion in boiling water, experiments made in 1876 having shown that the water contained in a foot-warmer so immersed is raised from a temperature of 32° to 194° in five minutes. This apparatus consists, first, of a tank in which immersion of the foot-warmers takes place; and secondly, of the mechanical arrangement for effecting this immersion with ease and regularity.

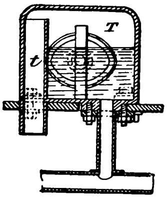
2104.



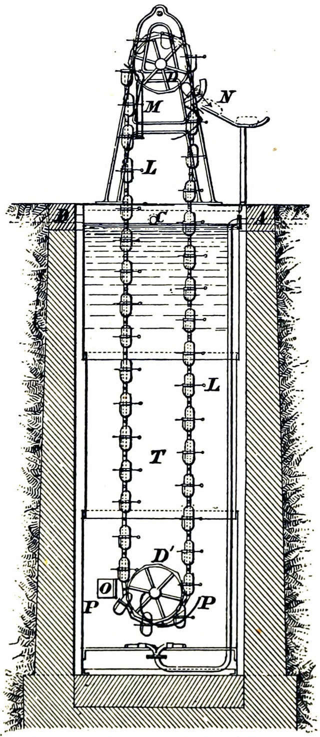
2105.



2106.



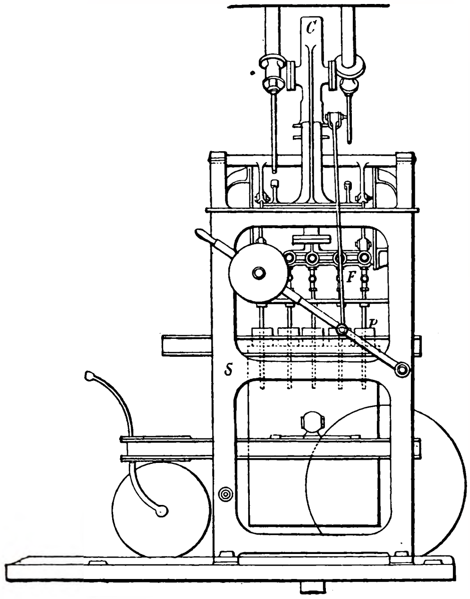
2107.



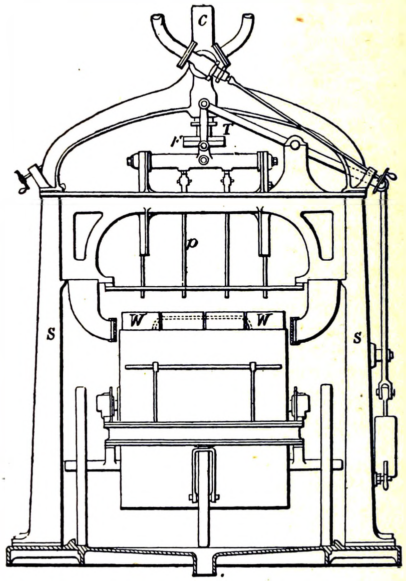
The tank T is 4 ft. 11 in. in diameter, and 15 ft. 1 in. deep; it is sunk below the surface of the ground, and is enclosed in a kind of well, which serves to protect it from the pressure of the earth. This tank is formed of wrought iron, the three rings of plates which compose it being respectively ·275 in., ·197 in., and ·118 in. thick. The top of the tank is closed by a cover, having in it openings to allow of the passage of the foot-warmers as they descend and ascend. The water in the tank T is maintained at boiling point by the injection of steam, this steam entering through a copper pipe A of 1·57 in. internal diameter; this pipe passes down to the bottom of the tank, and is there divided into two branches *a*, each 1 in. in diameter, these branches being perforated with a large number of small holes, a cock being provided on the pipe A to regulate the admission of steam. Besides the steam pipe A, the tank is provided with two other pipes; an overflow pipe at B to take away any excess of water, and another at C which serves to supply any water required to make up losses caused by evaporation, and by the water carried away by the emerging foot-warmers. The donkey pump, which supplies the boiler furnishing the steam for heating the water in the tank T, draws its supply from the said tank through the waste pipe B; the excess of water caused by the condensation of the steam used in heating is again fed back to the boiler, and the water thus travels in a circuit, it only being necessary to supply to the tank such an amount of fresh water as will make up for the losses above referred to; the cost of water for the operation of the apparatus is thus practically nil.

The arrangement for securing the regular immersion of the foot-warmers consists of a pair of endless chains, which pass over a polygonal drum D, mounted on a framing fixed over the top of the tank, and under another similar drum D′, at the bottom of the tank. Each chain consists of seventy-two links, the corresponding alternate links of the two chains being connected by crossbars, which serve to maintain the chains at the proper distance apart, and which also engage with corresponding teeth on the upper drum, and thus enable the latter to impart motion properly to the chains. The remaining alternate links of the two chains carry cages for the reception of the foot-warmers to be heated, these cages being so slung to the links that they may always hang vertically, except when intentionally diverted from this position to receive and discharge the foot-warmers. The lower drum under which the chains pass is so mounted that it is free to move vertically to some extent, it being, in fact, supported by the chains, and it can thus accommodate itself to the expansion and contraction of the latter. The upper drum is driven by gearing from the donkey pump which feeds the boiler supplying the steam for heating, the speed being so regulated that each foot-warmer is immersed for five minutes, twenty-four foot-warmers being immersed at one time. The cages, in which the foot-warmers to be heated are placed, are hung on axes taking their bearings in the alternate links of the chain; and on these axes levers L are mounted, and at M a kind of guide is fixed, which engages the levers and tilts the cage, so that the foot-warmers may readily be placed in them as they pass this point. At the point O near the bottom drum, there is a second stop which catches against the other ends of the levers and tilts the cages slightly, so as to ensure that the ends of the levers, which are towards the right, shall pass under

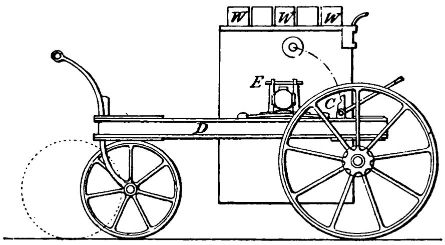
2108.



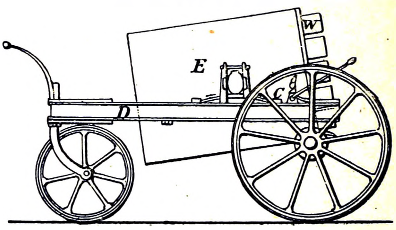
2109.



2110.



2111.



the guide curve P, this curve ensuring that the cages shall keep their proper positions, and not turn over and throw out the foot-warmers. Lastly, there is a guide provided at N, which engages with the ends of the lever and reverses the cages, thus causing the foot-warmers to be thrown out on to a table, from which they are removed by an attendant.

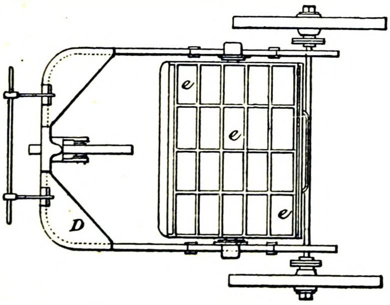
The total weight of the apparatus is 3 tons 12 cwt., the weight of the tank alone being 1 ton 10 cwt.; the cost, as given by the Eastern Railway Company, is as follows;—

	£
Construction of the well, and of the culvert in which the driving shaft is laid ..	56
Construction of the apparatus proper, with the driving gear and erection	120
Total	£176

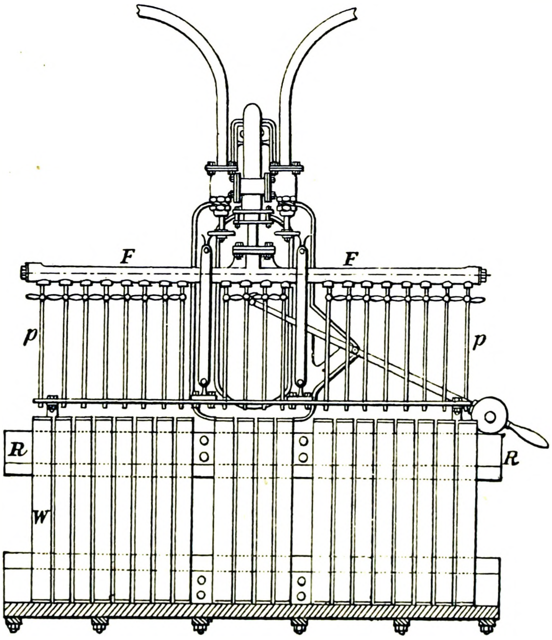
While, according to the experience of the above company, the cost of reheating each foot-warmer is almost exactly one halfpenny, this cost comprising all charges for the repairs and depreciation of the apparatus.

By the use of this apparatus, the necessity of emptying and refilling the foot-warmers in the manner followed in this country is entirely avoided. The foot-warmers are filled once for all, sufficient space being left for the expansion of the water when heated, and securely closed; and, as will have been seen from the above description, the cold foot-warmers are placed in the cages at M, they descend into the tank of boiling water and re-ascend to the discharging point N, where they are delivered properly heated. The immersion lasts five minutes, and as there are twenty-four foot-warmers immersed at once, it follows that the cages arrive at the charging point at intervals of twelve seconds; and this interval is found in practice to be amply sufficient to allow of the cages being regularly filled. As twenty-four warmers pass through the apparatus every five minutes, it is thus capable of heating $\frac{24 \times 60}{5} = 288$ foot-warmers an hour, or 6912 a day of twenty-four hours, a rate of working which is found to be amply sufficient for supplying the trains at the stations where the apparatus is in use. When used in connection with a boiler worked at 50-lb. pressure, it is found that this apparatus condenses about 4·4 lb. of steam for each foot-warmer heated to 194° F., and a boiler with 215 sq. ft. of surface is stated to be sufficient to keep up the steam supply. In steady work the steam supply required, according to the above figures, would be $288 \times 4 \cdot 4 = 1267 \cdot 2$ lb. per hour, corresponding to an evaporation of $\frac{1267 \cdot 2}{215} = 5 \cdot 9$ lb. per sq. ft. per hour for a boiler with 215 sq. ft. of surface; but this rate of evaporation is somewhat too high for economy, and if the heating apparatus had to be worked constantly, it would be preferable to provide a larger boiler; as, however, under the ordinary conditions of practice, the working of the apparatus is more or less intermittent, and as the water in the tank T contains a large reserve of heat, a boiler of the proportions above given is found to be sufficient.

2112.



2113.

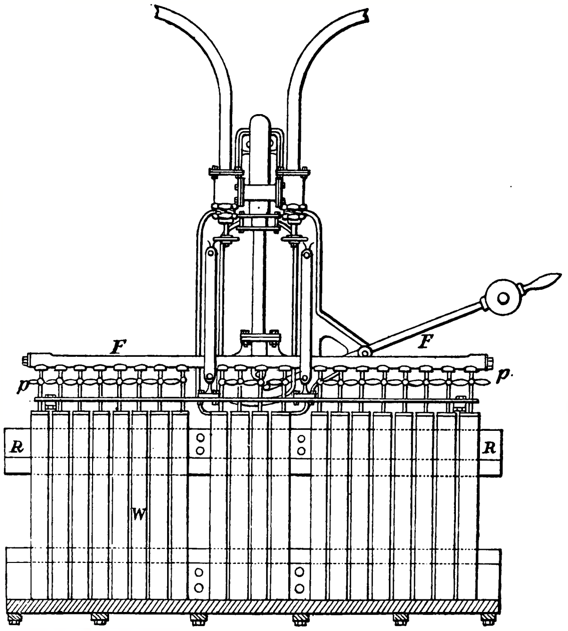


In Figs. 2108 to 2114 is illustrated the apparatus which is employed on the Paris, Lyons, and Mediterranean Railway, for filling and heating foot-warmers. With this apparatus the foot-warmers are reheated to about 185° F. by the injection of a jet of steam, which is a much more expeditious and less laborious plan than that of emptying the foot-warmers and refilling them with hot water.

The apparatus employed at large stations consists of a heater, Figs. 2108 and 2109, formed of a pair of cast-iron standards S, braced together at the top, and fitted with a sliding frame F, which can be raised or lowered by means of an arrangement of hand levers provided for that purpose. This sliding frame carries twenty hanging tubes *p*, arranged in five rows of four each, these tubes being all connected by horizontal tubes which place them in communication with a main central tube T, which rises from the centre of the sliding frame, and works in a stuffing box carried by the upper crossbar of the fixed frame. By means of this sliding joint, the main pipe of the sliding frame is placed in communication with a casting C, in which two cocks are fixed, one A serving for the supply of water, and the other B for the supply of steam. By this arrangement the twenty hanging pipes of the sliding frame can be made to discharge either steam or water into as many foot-warmers placed beneath them. The foot-warmers to be filled or reheated are carried by a tricycle, which is shown separately in Figs. 2110 to 2112. Each tricycle consists of a frame D, mounted on two carrying wheels with a guide wheel in front, this frame carrying a sheet-iron casing E, divided into compartments *e*, for receiving twenty foot-warmers W. The case E is mounted on trunnions, so that it can be brought into the position shown by Fig. 2111 for the convenient insertion or withdrawal of the foot-warmers, and can be turned up into the position shown in Figs. 2108 to 2110, to enable the warmers to be filled or heated, a catch *c* being provided for keeping it in either position. The mode of operating this apparatus is as follows;—A tricycle having been loaded with twenty-four foot-warmers, and the screw-plugs of these warmers having been removed, it is run into position under the filling apparatus, as shown in Figs. 2108 and 2109, and the sliding frame being depressed, each pendent pipe enters into the corresponding foot-warmer, which can either be charged with water, if empty, or the water in them can be reheated by the injection of steam. The process of reheating the water to a temperature of about 185° F. takes from three to four minutes; and one apparatus, such as shown, working in connection with a steam boiler having about 270 sq. ft. of heating surface, will reheat 240 foot-warmers per hour. When the foot-warmers are sufficiently reheated, the sliding frame with the pendent pipe is raised, the tricycle with its load run out of the way to make room for another, and the screw-plugs of the foot-warmers replaced, when they are ready for delivery into the carriages.

The arrangement adopted for secondary stations, Figs. 2113 and 2114, is similar in principle to that already described; but instead of being designed for reheating foot-warmers carried in groups on tricycles, it is arranged to deal with such warmers arranged in a single row in a rack R, which fixes their position with respect to the pendent pipes *p* of the sliding frame F. Fig. 2113 shows the apparatus with the sliding frame in its highest position, while Fig. 2114 shows it in its lowest position. Each pendent pipe *p* is furnished with a cock, as is also the case with the arrangement previously described, so that any number of pipes can be thrown out of use when desired. An apparatus of this type, worked in connection with a steam boiler having about 160 sq. ft. of heating surface, will reheat about 150 foot-warmers an hour.

2114.



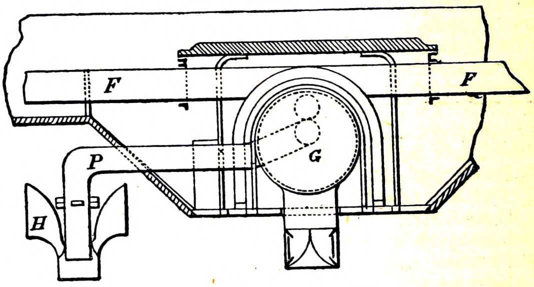
The following table, showing the length of line open, the number of locomotives, and various classes of rolling stock possessed by the principal British railways, on the 31st December, 1879; together with the cost for repairs and renewals from January 1st to December 31st of the same year; is selected from the reports on railways published by the authority of the Board of Trade for the year 1879.

NAME OF COMPANY.	Length of Line open Dec. 31, 1879.	Locomotives.	Carriages used for the Conveyance of Passengers only.	Other Vehicles attached to Passenger Trains.	Waggons of all kinds used for the conveyance of Live Stock, Minerals, or General Merchandise.	Any other Carriages or Waggons used on the Railway, not included in the preceding columns.	Total number of Vehicles of all descriptions for the conveyance of Passengers, Live Stock, Merchandise, Ballast, &c.
	Miles.	No.	No.	No.	No.	No.	No.
England and Wales:—							
Brecon and Merthyr Tydvil Junction	59	37	37	6	536	21	600
Cambrian	180	48	95	25	1,416	10	1,591
Cheshire Lines Committee	114		222	45	1,119		1,386
Festiniog	14	9	61	4	1,110		1,175
Furness	123	113	193	83	6,450	60	6,786
Great Eastern	938	569	1,561	816	10,955	489	13,821
Great Northern	717	637	1,406	440	15,406	1,637	18,889
Great Western	2,146	1,550	2,812	1,448	31,589	1,690	37,539
Lancashire and Yorkshire	473	713	1,826	383	18,534		20,743
London and North-Western	1,730	2,247	3,453	1,855	40,660	3,935	49,933
London and South-Western	719	404	1,534	596	6,104	534	8,768
London, Brighton, and South Coast	351	331	1,672	468	6,034	339	8,513
London, Chatham, and Dover	159	162	757	155	1,667	102	2,681
Manchester, Sheffield, and Lincolnshire	275	425	523	241	10,687	217	11,668
Maryport and Carlisle ..	41	25	31	15	1,582	9	1,637
Metropolitan	16	44	195		19		214
Metropolitan District ..	11	30	188		19		207
Midland	1,329	1,421	2,413	1,181	31,903		35,497
North-Eastern	1,474	1,364	1,880	709	73,039		75,628
North London	12	86	494	92	394	178	1,158
North Staffordshire	195	125	241	87	4,961	60	5,349
Somerset and Dorset ..	91	38	82	38	859	35	1,014
South-Eastern	334	298	1,481	468	4,285	292	6,526
Taff Vale	86	110	124	34	2,349	183	2,690
Scotland:—							
Caledonian	851	684	1,198	431	40,955	636	43,220
Glasgow and South-Western	325	280	619	205	11,022	304	12,150
Great North of Scotland	286	62	200	80	2,029	28	2,337
Highland	402	70	203	78	2,324	46	2,651
North British	940	511	1,249	434	26,035	152	27,870
Ireland:—							
Belfast and Northern Counties	151	44	126	42	1,117	31	1,316
Dublin, Wicklow, and Wexford	135	49	185	26	699	20	930
Great Northern of Ireland	494	126	273	156	2,705	123	3,257
Great Southern and Western of Ireland	478	152	272	161	3,037	127	3,597
Midland Great Western of Ireland	425	98	160	128	1,911	105	2,304
Waterford and Limerick	210	34	68	44	742		854

In Fig. 2115 is shown a vertical cross section of Thamm and Rothmuller's heating apparatus, which is very largely adopted in Austria; and the method for fixing the apparatus to the carriages is shown in Figs. 1966 and 1967.

By means of vertical and horizontal partitions, a kind of box or casing is formed beneath the underframe of the carriage, this casing containing, in the centre, the heating apparatus proper. This apparatus consists of a horizontal sheet-iron cylinder G, with a door at one end, and contains a cage or grated box for the fuel, this box having a cover of iron wire. The fuel employed consists of a mixture of charcoal and coke, and the air for supporting combustion enters through an ash pan riveted to the bottom of the cylinder G, the amount of air admitted being regulated by adjustable slides. From the inner end of the cylinder G, the products of combustion are led off through a copper pipe P, which passes out through the wooden casing, and is provided at its end with a kind of hood H, so constructed that the draught of air rushing through the hood, when the carriage is in motion, produces a current in the pipe P, and thus creates a draught through the apparatus. Over the cylinder G is placed a casing or mantle of sheet iron, of ∩ shape, which is provided with a couple of branch pipes or flues F, extending right and left to the bottom of the compartment; holes admit the cold air from the carriage to this casing, where it is warmed and returned to the carriage through the pipes above mentioned. The heat radiating from the apparatus and the pipes warms the air enclosed in the external casing, openings in the floor allowing this warmed air to ascend into the carriage. At the two sides of the apparatus are trumpet-mouthed tubes for collecting fresh air for admission to the carriage, these tubes communicating with a hollow protecting partition which is placed directly over the combustion cylinder, so as to protect the underframe from the heat radiated by the main part of the apparatus; and the fresh air, heated by traversing this partition, is admitted to the carriage through suitable ventilators; ventilators being also fixed near the ceiling of each compartment for the escape of the foul air, and for regulating the temperature.

2115.

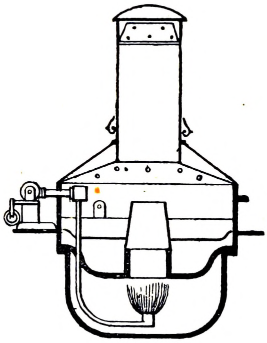


Twenty pounds of the mixture of coke and charcoal is found to be sufficient to maintain in a carriage, a temperature of 55° Fahr. during a run of twelve hours, whatever may be the external temperature, the apparatus requiring no attention during the run. This apparatus also affords good ventilation for the carriages, the temperature near the floor being always higher than near the roof. The arrangement and method of fixing this apparatus is such that access to the draw springs, and the like, is readily obtained.

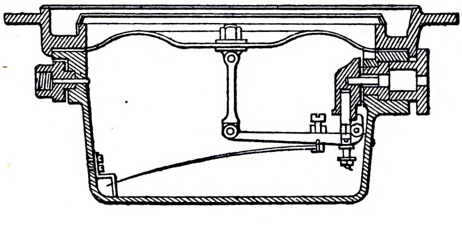
Lighting Railway Carriages.—Pintsch's oil-gas apparatus is illustrated in Figs. 2116 to 2118. This system of lighting is extensively employed.

The oil-gas making apparatus consists of banks of double-story retorts, 10 in. in diameter, arranged as in the section Fig. 2118. The oil, which may be any cheap hydrocarbon, is introduced in a small stream from a minutely adjustable cock, attached to a small cistern A, one of these cisterns being placed over each pair of retorts, into a funnel leading into an iron tray, which retains the oil until it is evaporated, and it then passes through the lower retort, in which the process of volatilization is completed. The adoption of this method of feeding in the oil makes the removal

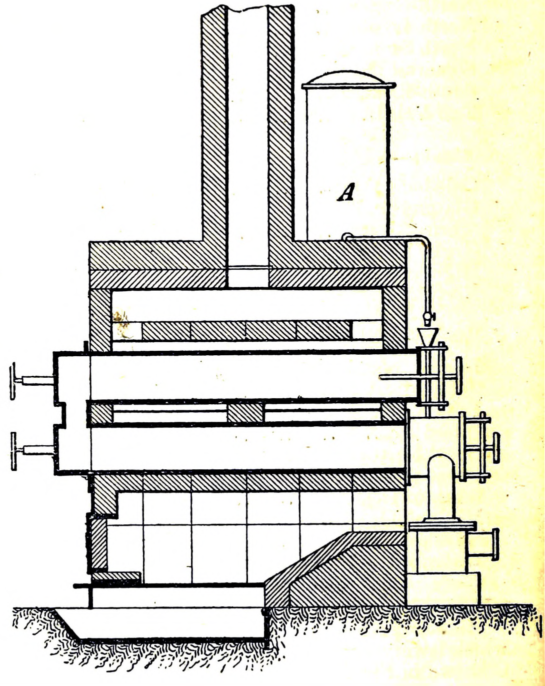
2116.



2117.



2118.



of the oil coke easy, prevents the cold oil from falling on to the hot iron of the retort, and permits the distillation of a larger quantity of oil than could be done in two separate retorts; and the arrangement moreover secures a higher temperature for the final conversion of the oil vapour into gas, and prevents the formation of smoke. One set of four retorts will produce, according to the quality of the oil, from 3500 to 4000 cubic feet of gas in ten hours, or sufficient for one light for 5000 hours, or if the retorts work continuously they produce enough for one light for 12,000 hours. The retorts are heated in the ordinary way by coke fires beneath. From the retorts the gas passes through a short length of pipe, past a tar well, and thence to a purifier of simple construction, carrying trays of sawdust and lime, and on to a gas-holder or gasometer. From this gasometer the gas is pumped as required and compressed by compressing pumps, which force it into reservoirs at a pressure of about ten atmospheres, these reservoirs varying in number according to the number of carriages which it may be necessary to fill at any one time. The pumps employed for compressing the gas into the reservoirs do not act directly on the gas, but on oil which rises and falls with the motion of the pistons. From the reservoirs the gas is passed from stand pipes, fitted with small strong cocks and very strong indiarubber hose, to the receivers placed under the frames of the railway carriages; and from these receivers it is led by stout $\frac{1}{4}$-in. pipes to the lamps in the roofs of the carriages.

The receivers, of which one or two are fitted to each carriage according to the length of journeys to be made, the length of the carriages, and the arrangement of the brake fittings, vary in diameter from 10 in. to 20 in., and in length from 5 ft. to 12 ft. These receivers must be well made and of the very best material, otherwise they become leaky under the constant vibration and jerking of the vehicle; the plates vary from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. in thickness, and are very carefully and slowly bent; while in addition to being carefully riveted and screwed, the end joints are afterwards soldered up and every rivet head and screw head soldered over, in order to secure a perfectly gas-tight vessel.

At a systematically arranged filling station, filling posts are placed at a distance apart equal to about that of the centres of the carriages of the ordinary lengths. Although the gas is compressed in the reservoirs up to ten atmospheres pressure, it is only passed into the carriage receptacles to a pressure of six atmospheres, as indicated by an attached gauge.

Between the carriage receivers and the roof lamps is placed the regulator, Fig. 2117, which constitutes one of the essential features of the whole design; and through this regulator the whole of the gas has to pass before reaching the lamps. This regulator consists of a cast-iron vessel, about 12 in. in diameter and 6 in. in depth; the upper part being closed by a membrane of specially prepared sheepskin, to the centre of which is fastened a rod connected at its lower end with the lever which controls the regulator valve; this lever is also controlled by a double-leaf spring acting in opposition to the membrane, and by this means the regulator valve is absolutely independent of the movements of the carriage, so that the accidental extinction of the light never takes place. The gas passes the valve, which is adjusted for a pressure of only that due to a $\frac{5}{8}$-in. column of water, and when this pressure under the membrane is reached the valve is closed, and the process of opening and closing is repeated until a balance between the admission and consumption is obtained.

From the regulator a $\frac{1}{4}$-in. pipe carries the gas to the roof of the carriage, a cock being provided by which all the lights may be extinguished at once; but separate cocks are fixed to each burner, so that one or all may be extinguished. No pipes larger than $\frac{1}{4}$ in. in internal diameter are employed, and all are very thick. The gas itself being very pure and permanent, no trouble has been experienced by the clogging of the pipes. Almost all the joints are made with small flanges, and no running sockets are used, the joint being made by a combined lead and indiarubber ring squeezed between the flanges.

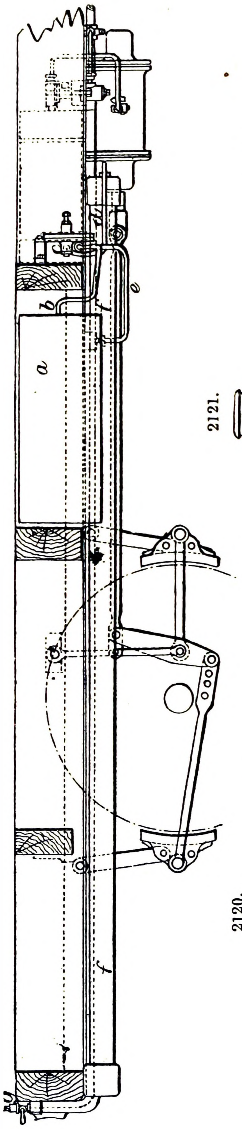
The lamps used with this system, Fig. 2116, are somewhat similar to those used for the coal-gas light, but the glass globe is smaller; the hole in the reflector is but a small slot, instead of a round, funnel-shaped chimney; and the reflector is convex instead of concave, as elsewhere used in lamps, and the light is therefore much more effectually dispersed. The bracket carrying the burner is hinged at the upper part, so that it may be turned up for cleaning the glass; while the glass bowls if broken can be replaced in a few minutes.

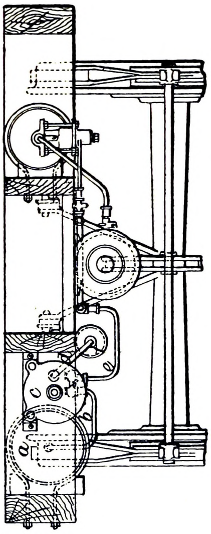
As regards the cost of lighting with oil gas; it was found by the London Metropolitan Railway Co. that the gas can be produced at the rate of 16*s*. 5$\frac{3}{4}$*d*. a 1000 ft., and that the consumption a light an hour is 0·5983 of a cubic foot. The cost of oil as compared with gas on this system is thus as 3·65 to 1. A further great source of saving which belongs to the use of high-pressure gas, arises from the length of time which each carriage supply will last. On the Metropolitan Railway it is usual to fill the coal-gas receivers at the end of each journey; the compressed oil-gas receivers are only filled once a day; the saving in labour, time, and leakage, from this difference alone is therefore very great.

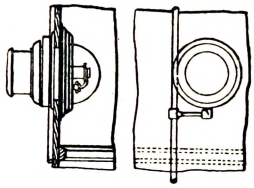
Figs. 2119 to 2125 relate to the apparatus designed by G. Westinghouse for lighting with gas; the apparatus being worked in connection with his brake. Fig. 2119 is a longitudinal section of a carriage, showing the form and size of the carburating reservoir, and the arrangement of pipes and regulator; Fig. 2120 is a cross section of same; Figs. 2123, 2124 are enlarged views of the regulator; Fig. 2122 a detail of the same; Fig. 2121 shows the lamp in the carriage with its connections; and Fig. 2125 is an enlarged view of the lamp, half in section.

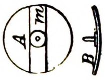
The carburator *f* is a tube about 6 in. in diameter and 12 ft. long, secured to the underframe of the carriage. At one end of the carburator is connected the regulator *c*, by which the admission of air to the carburator is controlled, and upon the action of which the proper working of the apparatus depends. The air passes through the regulator *c*, either from the main air pipe of the carriage, or from a small supplementary reservoir *a*, according to circumstances, and traverses the carburator *f*, which is filled with sawdust, cut sponge, felt, coke, or other suitable material, the whole being saturated with gasoline or similar oil. The air passing into the carburator under a suitable pressure at one end advances between the interstices of the material, and becomes changed into a rich illuminating gas by the time it reaches the other end of the carburator, a pipe *g* from which conducts it to the points of consumption.

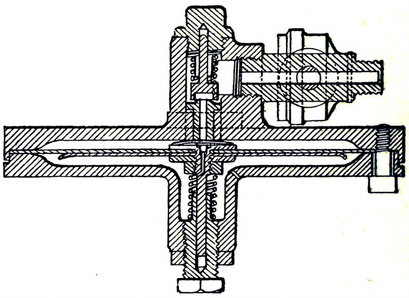
The regulator or reducing valve *c*, which is to an enlarged scale in Figs. 2123 and 2124, is circular, and made in halves, bolted together so as to enclose a shallow circular chamber, which is divided into two parts by means of a leather diaphragm bolted between the flanges of the regulator. This diaphragm is reinforced by a circular brass plate, the two edges of which are turned up, so that the leather shall not be injured; in the centre of this brass disc is fastened a small stem pierced with a minute hole, so as to establish a communication with both sides of the diaphragm, and extended so as to enter a hole formed in the screwed stud, the position of which can be

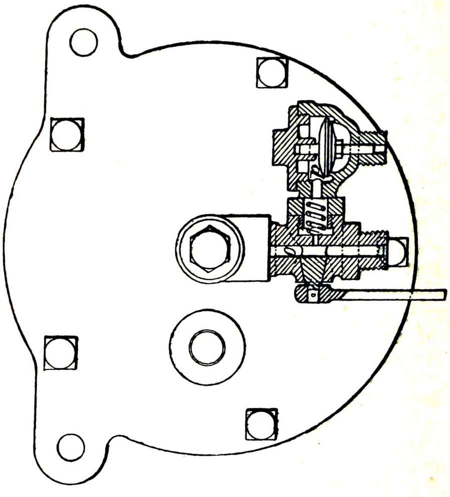

2119.

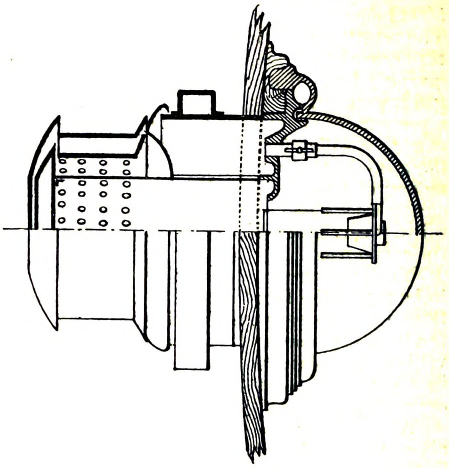

2120.


2121.


2122.


2123.


2124.


2125.

regulated from the outside. At its outer end the hole in this stud is enlarged to form the seating for a valve riveted to a curved spring and shown in Fig. 2124. In one half of the regulator casing, and on the outer side is a socket, through which passes the above-mentioned screwed stud, and is capable of compressing a spiral spring, which bears also against the centre portion of the diaphragm, or rather against a collar upon the stem *i*. On the other half of the casing is a projection, to which is secured a cock *o* and small valve chamber. The opening controlled by the valve *p* is that communicating with the main air pipe, the other goes to the supplementary reservoir *a* already referred to. A passage controlled by the cock, connects these passages with the chamber of the regulator; and another opening is used for letting the air pass on to the carburator.

It is customary, under ordinary circumstances, to draw the supply of air from the main pipe, and the supplementary reservoir is kept constantly full from the same source; but if from any cause, such as putting on the brakes, the pressure in the pipe is reduced, the air passing from the reservoir instantly shuts the clack valve *p* of the branch leading to the main pipe, and the carburator continues to be furnished from the cylinder till pressure is once more restored in the main pipe, and the check valve is reopened. The valve which serves to admit air in the regulator is shown at *j*, Fig. 2123. It consists of a stem which passes through a gland in the body of the regulator, and touches the spring of the small safety valve, when the latter is forced down by means of its own spring. The stem is reduced in section on two sides, so as to leave a passage for the air into the chamber *b*. To adjust the regulator for working the air admission valve is slightly opened by compressing the spring, which has the effect of forcing the valve on the stem slightly off its seat, and the second valve is closed, and at the same time partly closing the air admission valve, air then flows through the passage in the stem to the other side of the diaphragm, and escapes through a small hole in the casing. It is evident that the amount of air passed into the carburator can be exactly regulated by the amount of opening given to the admission valve, and adjusted by means of the outer screws. By closing the cock on the casing, the supply of air is shut off and the apparatus ceases to act; a tap is also placed on the pipe leading from the carburator to the lamps to shut off the supply if desired, and each of the lamps is furnished with a tap. The hemispherical glass depending within the carriage, is hinged to the framework on one side, and fastened with a spring lock on the other, so that the gas can be lighted with the utmost facility, and the lamps are not removed from their places. The top of the lamp forms a reflector, and distributes an even and very ample light through the carriage, which moreover leaves nothing to be desired in brilliancy and purity.

The carburators may be charged to last for two weeks without renewal, and the operation of lighting is simply that of turning a tap and applying a match, considerable time and risk of breakage and other damage are avoided.

SANITARY ENGINEERING.

The methods which have been proposed, or adopted, at various times, for getting rid of the excrete and other household and trade waste from a community are numerous. Of these we may enumerate burning, pneumatic conveyance, deodorization and disinfection by earth, and removal by water, each of which has its advantages, but none of these answer every requirement for the removal of town refuse effectually. Every one of these methods may, under certain circumstances, be utilized with advantage either separately or conjointly with water carriage, but it will be found that the latter system, properly carried out, is, where it can be adopted, the best adapted for the purpose. The works necessary for the drainage of a town are the drainage of the surface, that of the subsoil, and the removal of liquid and semi solid refuse. A drain is a conduit, intended only for the under drainage of the soil, and is made porous and open at the joints, so as to draw in as much water as possible, its purpose being to draw out of the land, through which it passes, the water which is in that land, and, as far as capillary attraction and other circumstances will permit, to thus remove the wetness caused by it. A sewer should have but one function to perform, that of conveying sewage, and therefore should be thoroughly water-tight, so as not to either leak into or receive water from the surrounding soil. In considering at large the question of draining a district the principal points to which attention should be directed are, the geological and physical characteristics comprised within the area to be dealt with, the water supply and the rainfall; with the proportion of the latter it is proposed to deal with by means of a sewer, the locality for the outfall, and the method of treatment proposed for sewage, together with correct estimates of both the present number of the population and its probable increase. The district must be carefully surveyed and the levels noted, whilst the same operation should be conducted with such portions of the surrounding neighbourhood as are likely to affect the plans. This is all the more necessary since it frequently happens that from its peculiar conformation the district may be liable to drainage from other areas which will materially affect its own system. Plans submitted to the English Local Government Board are usually prepared according to the following instructions, which are due to their eminent engineer, R. Rawlinson, C.B. A general plan exhibiting the area which will be affected by the proposed works, should be laid down to a scale of not less than 2 ft. to a mile. It should have figured upon it the levels of the centres of all streets and roads at their intersections and angles, and at every change of inclination. Where a district is near the sea it should show the high and low tide level of the sea, and where there is a river, the summer and flood water levels should be recorded. Permanent bench-marks, having reference to the surface levels, should be cut on public buildings throughout the district, and also be marked on the plan. Sections should accompany this plan, upon which the levels of the cellars should be shown. Such a plan might be used for showing lines of main sewers and drains, lines of water pipes and gas-mains. The lines of main sewers and drains should have the cross sectional dimensions and gradients distinctly marked upon them. The dimensions of water and gas pipes should also be shown in figures or by writing. A detailed plan for the purposes of house drainage, paving, or the sale and purchase of property, should be constructed to a scale of not less than 10 ft. to a mile. Upon this plan should be exhibited all houses and other buildings, bench-marks, the levels of streets and roads, of cellars, as well as the water levels previously mentioned. Three ft. by 2 ft. will be a convenient size for the sheets of this plan, and by representing the marginal lines of the sheets upon the general plan, this will become a very useful index. As it may occasionally be desired to carry out works piecemeal, with a view to save the time which would be occupied in the preparation of a complete plan from actual survey, it will be sufficient, in the first instance, to furnish a general plan of streets and roads only, with the surface levels, and those of the deepest cellars, and the proposed scheme of works shown thereon, after which the works can proceed in sections: but with each separate application for sanction to a loan, a correct plan and section or sections should be submitted, accompanied by detailed estimates and specifications. Plans of such schemes when submitted to the proper authorities, should be prepared to a scale of not less than 4 in. to the mile. Sections of the works should have a horizontal scale similar to that of the plan, with a vertical scale of at least 1 in. to 100 ft., and should any alterations be proposed in the water level of a canal, or in the level or rate of inclination of any public road or railway, cross sections must also be provided, having a minimum cross section of 1 in. to every 33 ft. and a vertical scale of 1 in. to every 40 ft.

Towns vary in character of site, as also in form of the surface contour, and, consequently, require differing modes of treatment in main sewering to pass subsoil, surface, and sewage waters safely. Some towns, as Portsmouth and Hull, situated on the margins of tidal estuaries, are, for the most part, low and flat, whilst other towns, like Brighton, Liverpool, and Sunderland, though also situate on the sea, or on shores of estuaries, have steep gradients, from which the water falling during heavy rains is accumulated and rapidly precipitated, to the destruction of the sewer inverts, by the extra scour and wear. Each area, therefore, requires special consideration, so as, in devising systems for main sewering, to enable the engineer to adopt such forms of works as shall facilitate the due and safe discharge of sewage, with the least injury to the sewers and to the inhabitants.

The admission or rejection of the rainfall from a system of sewers, depends entirely upon local circumstances. Particulars as to the quantity of rainfall likely to occur in a given locality, and other matters relating to the subject, have been already detailed at p. 3055 of this Dictionary.

In addition it may be fairly estimated that the sewers should provide for removing of rainfall an hour,

	Inches in depth.
From roofs	·5
,, flagged surfaces	·2
,, paved ,,	·1
,, gravel ,, clay subsoil	·05
,, ,, ,, gravel or chalk ditto	·01
,, meadows or grass plots	·02

In the open country, where the soil is loose and permeable, about one-third only of the rainfall finds its way into the watercourses, the remaining two-thirds being absorbed or evaporated.

In ordinary country towns, depending on the extent of the suburbs and the state of the pavements, from one-fourth to one-third of the rainfall due to a given period, should be provided to be removed by the sewers within one hour after it ceases. In large well-paved cities one-half of the quantity may be assumed as passing into the sewers within the same time.

Of sewage, the engineer should provide for removing 5 cubic feet a head of men, women, and children in 24 hours, one-half to be calculated as passing off in about 6 hours. The total quantity to be removed should never be estimated at less that the water supply.

The amount of solid matter in town sewage where the water supply is abundant, varies from 1 part in 300 to 1 part in 600.

As regards the number of the population to be provided for, in old and settled countries this is not a difficult matter, since the census returns are generally accessible and fairly accurate. In England the population may be readily estimated by ascertaining the number of inhabited houses, and multiplying this by the average number of inhabitants who were found to dwell in each house at the last census. This may also be approximately arrived at by estimating that six persons inhabit each house.

To determine accurately the size and inclination of the common sewers it may be intended to construct, it is necessary to have reference to the amount of foreign water and solid matter which will be brought into them in addition to the quantity and the character of the sewage proper. A velocity of 60 ft. a minute will be sufficient for the discharge of clear sewage closely approximating to the character of water, and sewage strained of its coarser particles will flow without deposit with a velocity of 90 ft. a minute. Ordinary sewage requires a mean velocity of 150 ft. a minute. Wicksteed's experiments showed that a mean velocity of 137½ ft. a minute would suffice for the removal of heavy sewage matter when the sewer was running full or half full, but it is necessary to have a velocity in large sewers of 2 miles an hour, or 176 ft. a minute, when running three quarters full, 165 ft. when running half full, and 146 ft. a minute when running one-third full. Beardmore laid it down in his 'Manual of Hydrology,' that the following bottom velocities have the effect stated on the different materials particularized:—

30 ft. a minute will not disturb clay with sand and stones.
40 ,, ,, will move along coarse sand.
60 ,, ,, ,, ,, fine gravel, size of peas.
120 ,, ,, ,, ,, rounded pebbles, 1 in. diameter.
180 ,, ,, ,, ,, angular stones, 1¾ in. diameter.

Bottom velocity, which imparts the greater motion, differs from mean velocity in the ratio of from ·75 to ·85—say ·80 to 1—or four-fifths. The greatest discharge from a circular conduit is when it is not quite full, that is, when rather better than fifteen-sixteenths full, and the greatest velocity occurs when it is thirteen-sixteenths full.

A 2-ft. sewer, if discharging clear sewage with a velocity of 60 ft. a minute, would require a fall of rather more than 1 foot a mile; if discharging strained sewage with a velocity of 90 ft. a minute, $2\frac{1}{2}$ ft. a mile; and if discharging ordinary unscreened sewage with a velocity of 150 ft. a minute, a fall or inclination of $7\frac{1}{2}$ ft. a mile.

Table I. gives the velocities of water flowing through and the quantity discharged from circular pipes or culverts a minute when laid at different inclinations, and running half and three-quarters full.

This Table is calculated from Beardmore's formula, which has been found to be very reliable:

$$V = 55\sqrt{R \times 2H}.$$

R = hydraulic mean depth in ft.
H = fall in feet a mile.
V = velocity in feet a minute.

It may be desirable here to give the formulæ of the four different foreign authorities principally recognized.

Du Buat's formula reduced to English measure:—

$$V = \frac{307(\sqrt{R} - 0\cdot1)}{\sqrt{S} - L(\sqrt{S + 1\cdot6})} - 0\cdot3(\sqrt{R} - 0\cdot1).$$

V = velocity in inches a second.
R = hydraulic mean depth = $\frac{1}{4}$ diameter in inches.
S = slope or difference of level.
L = hyperbolic logarithm, and found by multiplying the common logarithm by 2·3026.

In the following formulæ English feet are employed;—

V being the velocity a second.
D „ diameter
H „ head or pressure } of the pipe.
L „ length

Prony's simple formula:—

$$V = 48\cdot449\sqrt{\frac{DH}{L}}$$

Eytelwein's formula, as given by Tredgold:—

$$V = 45\cdot5\left(\sqrt{\left(\frac{DH}{L + 47D}\right)}\right).$$

Poncelet's formula:—

$$V = 47\cdot95\sqrt{\left(\frac{DH}{L + 54D}\right)}.$$

The quantities afforded by these formulæ were tested by actual discharges and the results as tested by Murray, are detailed in Table II. The calculated discharges are given by Du Buat, Prony, Eytelwein, and Poncelet respectively.

TABLE I.—DISCHARGE OF SEWERS.

Diameter of Pipe.	Length.	Head or Pressure.	Discharge a Minute.	Calculated Discharge a Minute.
in.	ft.	ft.	cub. ft.	cub. ft.
2·	3,300	12·75	1·617	1·507
				1·609
				1·509
				1·59
4·5	14,930	51·00	11·333	11·252
				11·491
				10·784
				11·281
12·789	3,837	12·90	155·	158·
				155·
				145·
				141·
12·789	14,963	21·582	111·	99·
				102·
				99·
				98·
19·184	5,052	4·929	217·	223·
				230·
				215·
				226·
30·	5,280	9·00	880·	926·
				932·
				865·
				910·

The area of an egg-shaped sewer is found accurately by squaring the radius of the top, and multiplying this by 4·6.

To find the sectional area of the brickwork, inclusive of the invert, the following formulæ, as well as table, have been worked out by Henry Hobson;—

Let S = equal the sectional area, and let t = the thickness of the brickwork.

$$\therefore \mathrm{S} = \frac{\pi\,(r+t)^2 - \pi\,r^2}{2} + 2\left\{\frac{(3\,r+t)^2\,\theta}{2} - \frac{(3\,r)^2\,\theta}{2}\right\}$$

$$+ \left\{\left(\frac{r}{2}+t\right)^2 \cdot \left(\frac{\pi}{2}-\theta\right) - \left(\frac{r}{2}\right)^2 \cdot \left(\frac{\pi}{2}-\theta\right)\right\}$$

$$= \frac{\pi}{2}(2\,r\,t+t^2) + \theta\,(6\,r\,t+t^2) + \left(\frac{\pi}{2}-\theta\right)\cdot(r\,t+t^2)$$

$$= \pi\,t^2 + r\,t\left\{\frac{3\,\pi}{2} + 5\,\theta\right\}$$

$$\doteq \pi\,t^2 + r\,t\left\{\frac{3\,\pi}{2} + \frac{5\times\pi\times 36{\cdot}87}{180}\right\}$$

$$= \pi\,t\,\{\,t + (r\times 2{\cdot}5241\dot{6})\,\}$$

$$= 3{\cdot}14159 \times t\,\{\,t + (r\times 2{\cdot}5241\dot{6})\} \cdot \qquad (a)$$

The sectional area thus found, when expressed in square yards, will give the number of cubic yards of brickwork in the sewer a lineal yard.

The sectional area of the invert $a\,b$ may be found separately, thus:

$$\mathrm{S} = \left\{\left(\frac{r}{2}+t\right)^2 \cdot \left(\frac{\pi}{2}-\theta\right)\right\} - \left(\frac{r}{2}\right)^2 \cdot \left(\frac{\pi}{2}-\theta\right)$$

$$= (r\,t+t^2)\cdot\left(\frac{\pi}{2}-\theta\right)$$

$$= (r\,t+t^2)\cdot\left(\frac{\pi}{2}-\frac{36{\cdot}87+\pi}{180}\right)$$

$$= (r\,t+t^2)\cdot\left(\frac{53{\cdot}13\times\pi}{180}\right)$$

$$= t\,(r+\ )\times {\cdot}9273 \text{ nearly.} \qquad (b)$$

The sectional area thus found, when expressed in square yards, will give the number of cubic yards of brickwork in the invert a lineal yard.

Table II. is intended to show the results of the formulæ, whilst it gives the sectional areas of all sizes of egg-shaped sewers likely to be constructed. No opinion is expressed either as to the limits of size above or below which it may be advisable to construct sewers having an egg-shaped cross-section, or as to the thickness of brickwork suitable; it will be seen that extreme cases have been included.

The cubic contents of the brickwork have been calculated from (a), and include the invert. The cubic contents of the inverts alone may be found from (b) and deducted from the amounts given in the Table if it be desirable to do so in any particular case.

The areas and quantities have been computed to the nearest decimal.

Table II.—Sectional Areas of Egg-shaped Sewers.

R.	Dimension of Sewer in inches.	Area of Sewer in sq. ft.	Brickwork in cub. yards a yard run.		
			4½″ Work.	9″ Work.	13½″ Work.
6″	12 × 18	1·150	·214	·527	
7	14 × 21	1·565	·242	·582	
8	16 × 24	2·044	·269	·637	
9	18 × 27	2·587	·297	·692	
10	20 × 30	3·194	·324	·747	
11	22 × 33	3·865	·352	·802	
12	24 × 36	4·600	·379	·857	
13	26 × 39	5·400	·407	·912	
14	28 × 42	6·261	·434	·967	
15	30 × 45	7·187	·462	1·022	
16	32 × 48	8·178	·490	1·077	
17	34 × 51	9·232	·517	1·132	
18	36 × 54	10·350	·545	1·188	
19	38 × 57	11·532	·572	1·243	
20	40 × 60	12·778	·600	1·298	2·094
21	42 × 63	14·087		1·353	2·176
22	44 × 66	15·461		1·408	2·259

R.	Dimension of Sewer in inches.	Area of Sewer in sq. ft.	Brickwork in cub. yards a yard run.		
			4½″ Work.	9″ Work.	13½″ Work.
23	46 × 69	16·898		1·463	2·342
24	48 × 72	18 400		1·518	2·424
25	50 × 75	19·965		1·573	2·507
26	52 × 78	21·594		1·628	2·589
27	54 × 81	23·287		1·683	2·672
28	56 × 84	25·044		1·738	2·755
29	58 × 87	26·865		1·793	2·837
30	60 × 90	28·750		1·848	2·920
31	62 × 93	30·699		1·903	3·002
32	64 × 96	32·711		1·958	3·085
33	66 × 99	34·788		2·014	3·168
34	68 × 102	36·928		2·069	3·250
35	70 × 105	39·132		2·124	3·333
36	72 × 108	41·400		2·179	3·415

Table III., relating to egg-shaped sewers, by J. T. Hurst, and given in his Pocket-book, shows the discharge in cubic feet a second when the diameter of the larger circle C and the inclination are given, the sewer flowing two-thirds full, calculated from the formula, $2 = 35\sqrt{d^5\frac{f}{l}}$, d being the diameter C in feet. Five-sevenths of the quantity given in this Table will equal the discharge from cylindrical pipes of the same diameter when flowing two-thirds full.

Table III.—Discharge of egg-shaped Sewers.

Diameter in feet and inches.		Fall divided by Length.											
		$\frac{1}{10000}$	$\frac{2}{10000}$	$\frac{3}{10000}$	$\frac{4}{10000}$	$\frac{5}{10000}$	$\frac{6}{10000}$	$\frac{7}{10000}$	$\frac{8}{10000}$	$\frac{9}{10000}$	$\frac{1}{1000}$	$\frac{2}{1000}$	$\frac{3}{1000}$
′	″												
0	9	·17	·24	·30	·34	·38	·42	·45	·48	·51	·54	·76	·95
1	0	·35	·49	·61	·70	·78	·86	·93	·99	1·05	1·11	1·57	1·92
1	3	·61	·86	1·06	·22	1·37	1·50	1·61	1·73	1·83	1·93	2·73	3·35
1	6	·96	1·36	1·67	1·93	2·16	2·36	2·55	2·73	2·89	3·05	4·31	5·22
1	9	1·42	2·01	2·46	2·84	3·17	3·47	3·75	4·01	4·25	4·48	6·34	7·77
2	0	1·98	2·80	3·43	3·96	4·43	4·85	5·24	5·60	5·94	6·26	8·85	10·84
2	3	2·66	3·76	4·60	5·32	5·94	6·51	7·03	7·52	7·93	8·40	11·89	14·56
2	6	3·46	4·89	5·99	6·92	7·73	8·47	9·15	9·78	10·38	10·94	15·47	18·94
2	9	4·39	6·21	7·60	8·78	9·81	10·75	11·61	12·41	13·17	13·88	19·63	24·09
3	0	5·46	7·72	9·45	10·91	12·20	13·36	14·44	15·43	16·37	17·25	24·40	29·88
3	6	8·02	11·34	13·89	16·04	17·94	19·65	21·22	22·69	24·06	25·37	35·87	43·93
4	0	11·20	15·84	19·40	22·40	25·04	27·43	29 53	31·68	33·60	35·42	50·09	61·34
4	6	15·03	21·26	26·04	30·07	33·62	26·83	39·78	42·52	45·10	47·54	67·24	82·35
5	0	19·57	27·67	33·89	39·13	43·75	47·93	51·77	55·34	58·70	61·87	87·50	107·2

Diameter in feet and inches.		Fall divided by Length.										
		$\frac{4}{1000}$	$\frac{5}{1000}$	$\frac{6}{1000}$	$\frac{7}{1000}$	$\frac{8}{1000}$	$\frac{9}{1000}$	$\frac{1}{100}$	$\frac{2}{100}$	$\frac{3}{100}$	$\frac{4}{100}$	$\frac{5}{100}$
′	″											
0	9	1·08	1·21	1·32	1·43	1·52	1·62	1·70	2·41	2·95	3·41	3·81
1	0	2·21	2·47	2·71	2·93	3·13	3·32	3·50	4·95	6·06	7·00	7·83
1	3	3·87	4·32	4·74	4·91	5·47	5·80	6·11	8·65	10·59	12·23	13·67
1	6	6·10	6·82	7·47	8·07	8·63	9·15	9·64	13·64	16·71	19·29	21·57
1	9	8·97	10·03	10·98	11·86	12·68	13·45	14·18	20·05	24·56	28·36	31·71
2	0	12·52	14·00	15·34	16·56	17·71	18·78	19·80	28·00	34·29	39·60	44·27
2	3	16·81	18·79	20·59	22 24	23·78	25·21	26·58	37·59	46·03	53·16	59·43
2	6	21·88	24·46	26·79	28·94	30·94	32·81	34·59	48·92	59·91	69·18	77·34
2	9	27·76	31·04	34·00	36·72	39·26	41·67	43·89	62·07	76·03	87·79	98·15
3	0	34·51	38·58	42·26	45·65	48·80	51·76	54·56	77·16	94·50	109·1	122·0
3	6	50·73	56·72	62·13	67·11	71·74	76·10	80·21	113·4	138·9	160·4	179·4
4	0	70·83	79·20	86·75	93·71	100·2	106·3	112·0	158·4	194·0	224·0	250·4
4	6	95·09	106·3	116·5	125·8	134·5	146·6	150·3	212·6	260·4	300·7	336·2
5	0	123·7	138·3	151·6	163·7	175·0	185·6	195·7	276·7	338·9	391·3	437·5

House drains leading from water-closets should be 6 in. diameter, and laid with a fall of not less than 1 in. in 10 ft., and where possible 1 in. in 5 ft. Branch drains from sinks may be 4 in. diameter, with a fall of 1 in. in 6 ft.

A velocity of about 3 ft. a second is required to keep house drains clear and 2 ft. a second for main sewers. These velocities should be increased for small pipes, say, for house drains under 6 in. diameter, and for mains under 12 in. diameter.

Table IV. shows the fall to be given to cylindrical sewers flowing one-half full to ensure these velocities.

TABLE IV.—FALL FOR CYLINDRICAL SEWERS.

Diameter of Sewer.	Velocity 2 ft. a second,	Velocity 3 ft. a second.	Diameter of Sewer.	Velocity 2 ft. a second.	Velocity 3 ft. a second.
inches			inches		
4	1 in 200	1 in 100	15	1 in 700	1 in 350
6	1 in 300	1 in 150	18	1 in 900	1 in 450
9	1 in 450	1 in 225	24	1 in 1200	1 in 600
12	1 in 600	1 in 300	30	1 in 1400	1 in 700

Except where sewage is used for irrigation, all rain water should, as a rule, be allowed to pass off by the sewers, for the purpose of flushing them.

The formula used for calculating the size of open channels and pipes for water supply applies also to sewers, except that the latter are usually taken as flowing from one-half to two-thirds full. In which case the value of R must be found by dividing the area of the transverse section of the part filled by the girth of the bottom and sides which are in contact with the sewage. In cylindrical pipes, flowing one-half full, R = one-fourth of the diameter, the same as for pipes entirely filled; when the sectional area of the sewage is two-thirds that of the pipe, $R = \text{diameter} \times 292$; and when three-fourths, $R = \text{diameter} \times 296$.

For egg-shaped sewers, of which the conjugate diameter is 1½ time the transverse diameter, when flowing about two-thirds full, the following formula may be used.

$$V = 15{\cdot}3 \sqrt{d S},$$

$$Q = 11{\cdot}56 \sqrt{d^5 S},$$

d being the transverse diameter in inches.

Other forms of sewer may be calculated by the formulæ for open channels.

The natural drainage contours of a district are usually best adapted for the main lines of sewers and the same levels will also give the lines in which storm water overflows will have to be constructed. Ordinary sewers are usually laid in straight lines, and a manhole arranged wherever a lateral deviation occurs, whilst lamp holes or ventilators are requisite at every point where the sewers deviate vertically, which are subject to a change of gradient.

Figs. 2126 to 2146 afford illustrations of these arrangements.

The materials used for sewers consist of bricks laid in cement or hydraulic lime mortar, stoneware pipes, and concrete, used separately, or in conjunction with bricks and pipes. Iron also is used where the sewer has to be taken through unsound ground, under rivers, and in special cases through closely inhabited districts.

In the construction of brick sewers bricks of the best quality should be used. They need not necessarily be radiated bricks, but they should be well burnt and well shaped, and possess adhesive qualities; for although the pressure of the outer earth upon the sewer may be greater than the internal pressure of the sewage outwards when the sewers is full, it is not the less necessary that the cement or hydraulic lime mortar in which the bricks are laid should adhere to the bricks where a water-tight condition of sewer is a paramount object. Ill-burnt and soft bricks should be most stringently rejected. Rough bricks, even if well shaped and well burnt, should not be used for the internal lining of sewers, as the suspended matters of the sewage will cling to them, and ultimately coat them with putrescible substances. The London stock brick forms a very good sample of a suitable brick for sewers. Some engineers prefer the Gault brick, but though it possesses a comparatively smooth surface, and therefore can be advantageously used for the inner lining, its lack of adhesiveness does not recommend it. The blue Staffordshire bricks and fireclay bricks glazed on one edge, form superior inverts, and being very hard, strong, and smooth, will resist erosion. They are to be preferred to the glazed invert blocks, which have been much recommended by some persons. Figs. 2149, 2160, 2163 are various sections of brick sewers.

The cement or lime used for the mortar in the building of brick sewers should be selected with great care. The former should be Portland cement weighing from 110 lb. to 112 lb. to the striked bushel, and it should be used in the proportion of 1 of cement to 1 of clean washed sand. If lime be used at all, it should be the best hydraulic or blue lias lime. Roman cement, which sets more quickly than Portland cement, may be usefully applied as an inside rendering. There is nothing connected with the construction of brick sewers of more consequence than the mixing of either cement or lime mortar, and when properly mixed it should be used immediately.

If the sewer is constructed below the ordinary level of subsoil water, the utmost care is required to keep the work in hand above water by pumping until the cement or lime has become set.

None but the best-formed and burnt stone or earthenware pipes ought to be used for sewers of any size. Stoneware pipes are to be preferred to those made of fireclay, though if the latter are well made and well burnt they are very suitable.

The thickness of fireclay pipes should be greater than that of the best stoneware. With the latter, the thickness should never be less than one-twelfth of the internal diameter. In the smaller sizes this proportion must be increased. A 4-in. pipe, for instance, should be at least half an inch thick, while a good 18-in. pipe need not be more than $1\frac{1}{2}$ in. thick. The depth of the socket should increase with the diameter of the pipe, nothing less than $1\frac{1}{2}$ in. being sufficient in the smaller pipes, and something more than 2 in. being desirable when the diameter exceeds 12 inches.

In laying both the stoneware and the earthenware pipes, the joints should in all cases be caulked and tarred with gaskin, and laid and finished with cement, or in some cases clay, in order that they may be water-tight. If the cement or clay cracks, which it may do, the gaskin may preserve the water-tight condition of the joint, and is very effective in excluding sand, even if subsoil water should penetrate. Great care is necessary to prevent the pipes moving before the cement has become perfectly set.

Although the preferable joint may be made of tarred gaskin and cement, many engineers consider that if the jointing is carefully performed, puddled clay is all-sufficient for the purpose; that eminent authority, J. Bailey Denton, is however of opinion that this material cannot be depended upon. When the soil is either always dry, or at one time comparatively dry and at another wet, and such conditions of soil, it should be borne in mind, invariably prevail to some extent in the sites of all towns, clay is the worst jointing material that can be used. In winter the subsoil water rising in the ground will probably keep the soil surrounding the sewers moist and the clay puddle in a state of expansion, while in summer the reverse condition will prevail; the subsoil water will then sink from the effects of evaporation, the soil will become dry to the invert of the sewer, and the clay puddle will contract and let the sewage out of the sewer. When once this natural result has been produced, all chance of a water-tight condition recurring will be destroyed. If a sewer is jointed with clay puddle at no greater depth than 5 ft. from the surface, it must inevitably be leaky.

Particulars relating to earthenware pipes have already been given at p. 2656 of this Dictionary. With regard to best Portland cement, pipes made of this material are about the same expense as the best earthenware. The smaller are rather more expensive than earthenware pipes of the same size. They have, however, some advantage not possessed by pipes that have been subjected to great heat in the course of manufacture, that is, they are perfectly true in section. The pipes are made of one part of best Portland cement to three parts of prepared ballast, with only sufficient water to effect the proper admixture, and subsequently mechanical means are adopted for filling the wrought-iron moulds, which secures the complete filling of the moulds without the presence of air holes. After the pipes have been thus prepared they are submerged in a bath of silicate of soda. By this means any free lime or alumina would thus form insoluble compounds of silicates of lime or alumina. In the jointing of a cement pipe with cement, there is a considerable advantage; a simple ogee rebated joint in a cement pipe when luted with neat cement requires a very considerable force to draw the pipes asunder, and answers every purpose. The material of which a cement pipe is made is by no means brittle, as a blow that would shiver an ordinary earthenware pipe would simply drive a hole into a silicated concrete pipe. A concrete pipe is capable of withstanding the jars arising from heavy traffic over the streets even better than an earthenware pipe, but its value very much depends upon the intelligence and care with which the concrete is manipulated.

When laying pipe sewers, to be jointed either with cement or clay, care should be taken to hollow out the bottom of the trench at each joint, so that the full length of the pipe between joint and joint may have a perfect bearing on solid earth. Much depends upon the laying of the pipes in true position. Wherever the size of the pipe will admit of it, a man or boy should be employed inside the pipes as they are being laid, to make good, with some of the best of the jointing material, the inside of the joint.

If there is any doubt about the efficiency of the tarred gaskin and cement to form a perfect joint, a band of concrete must be resorted to as an additional precaution.

In Figs. 2147, 2148, illustrations are given of sewers formed of a ring of $4\frac{1}{2}$-in. brickwork surrounded by concrete. Ballast of a very clean description, and cement of the best quality, well mixed in the proportion of 8 of ballast to 1 of cement, and quickly used, will give a very fair result; though where there is any doubt as to the quality of the constituents, the proportions may be advantageously altered to 7 or 6 to 1. The composition may also consist of mortar, made in the proportion of 3 of sand to 1 of good hydraulic lime, mixed with the same bulk of shingle or washed gravel. When prepared, it should be rammed into form while in a wet condition, and it is better to use the concrete in too wet rather than in too dry a state.

There will seldom be a sewage work, however small, in which iron pipes will not be used in some parts of the works, either in crossing under rivers, or from one side of a valley to the other, or in passing through unsound ground, or in other special cases. To secure the requisite thickness of iron pipes for any special purpose, it is desirable to make a liberal allowance for possible defects, and all pipes should be tested before use by hydraulic pressure. It has been laid down that the resistance which a pipe offers to the internal pressure tending to burst it, is equal to the cohesive strength of its two sides, and the effective area of pressure is the internal diameter of the pipe, and some very useful data upon this subject have already been given in this Dictionary.

Wrought-iron tubes are very useful for special crossings where a girder form of construction can be adopted, such as, for instance, when crossing rivers where supporting piers would be objectionable.

One method of crossing a river is to support the tube by brick piers and concrete; the tube being wholly surrounded by concrete in its bed under the river. Between the flanges of the tube vulcanized indiarubber washers three-eighths of an inch thick are placed, and these are screwed together by five-eighths bolts and nuts.

Two other means of crossing under rivers by iron pipes, are by tubing in a straight line from chamber to chamber, and by a deflection. In the latter case, a chain may be placed inside which may at any time be drawn backwards and forwards so as to stir and set in motion any sedimentary substances which might possibly deposit themselves and adhere to the pipes.

There have been objections raised from time to time to the taking of sewers under rivers by inverted syphons or deflected pipes, but they have been advanced more from prejudice than from positive experience. In many important towns, in this and other countries, sewage has been taken by these means from one side of a river to the other without difficulty.

The following brief memoranda as to materials is due to R. Rawlinson:—

The bricks to be used in sewer construction should be well burned and sound. For circular and egg-shaped sewers the bricks should be specially moulded to suit the radius lines the beds must take in the work. All bricks should be thoroughly wetted before use.

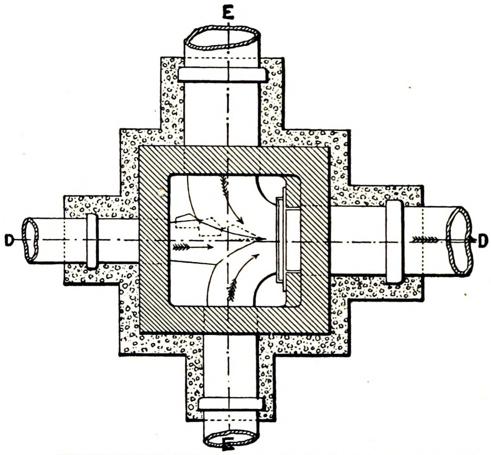
Mortar for sewer works in all cases should be capable of setting in water. Portland cement and lias limes make good hydraulic mortar. The proportions of cement, or of lime to sand, should not exceed 2½ of clean sharp sand to 1 by measure of ground Portland cement or lias lime. If clean furnace ashes or slag are available, there may be 2 of sand and ½ of ashes or slag, the whole to be mixed in a revolving pan, each panful to have 20 minutes' grinding.

Concrete should be made with Portland cement, with lias lime, or with other equally good hydraulic lime, in the proportions as under.

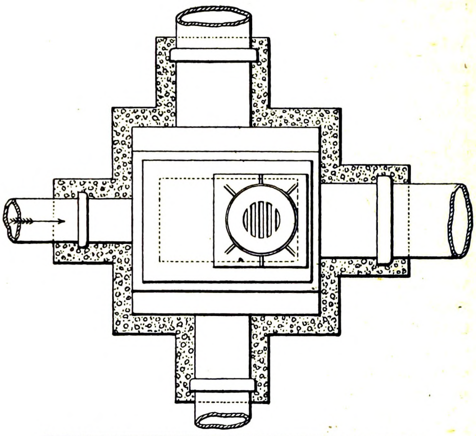
For the best concrete, out of which to mould manhole inverts or to form sewers, let the proportions be 5 of gravel and sand to 1 of fresh cement or lime by measure.

For foundations, backing to side walls, and coverings to arch spandrils, the proportions may be 7 of gravel and sand to 1 of fresh cement or lime by measure.

2126.



2127.



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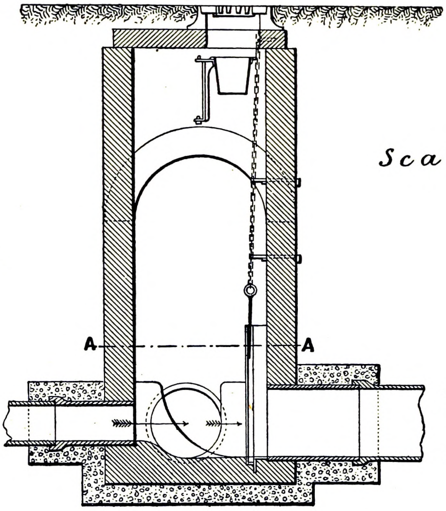
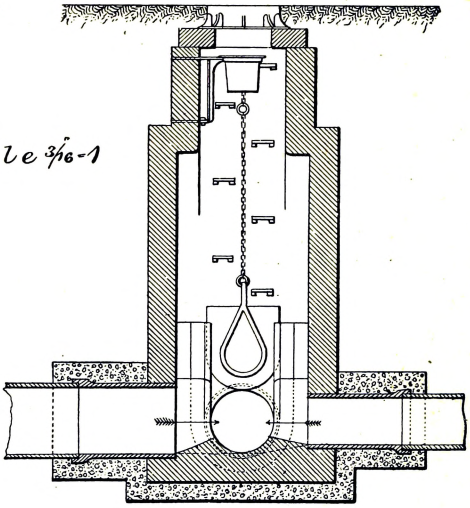


2128.



2129.

Concrete for filling in trenches over sewers and drains, or where required in large masses for foundations, may be made with 9 of gravel and sand to 1 of fresh cement or lime by measure.

The gravel may be substituted or be mixed with broken stone, broken tiles, or broken bricks, the largest portions be capable of passing through a ring of 1¼ in. in diameter. The sand should be clean, sharp, and in the proportion of 1 to 3 of the gravel. The whole lime, gravel, and sand should be fully mixed in a dry state, and then be wetted by sprinkling with water, preparatory to being placed in the work.

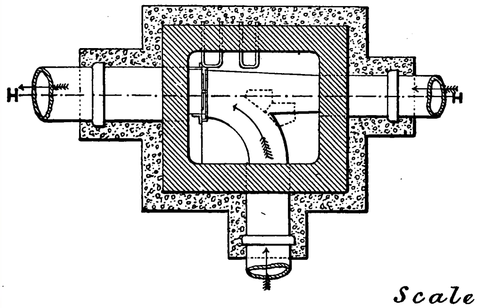
Where concrete is substituted for brickwork in retaining walls, or in walls of tanks and reservoirs, the concrete should be one-third thicker than brickwork, that is, where a retaining wall is required to be 3 ft. thick if of brickwork, it should be 4 ft. thick if of concrete.

Retaining walls to be safe should have cohesion and gravity equal, at the least, to four times the moving weight to be retained, and should have drains through their substances, from back to front, to permit of drainage, and prevent any accumulation of water behind the retaining wall.

When mortar is used with bricks, the beds and joints should be spread thick and full over the entire area of both bed and joint, leaving, when pressed into place, a bed and joint never less than one-eighth of an inch in thickness of mortar. In 4 cubic yards of completed brickwork there should not be less than 1 cubic yard of mortar incorporated.

Portland cement concrete and mortar may be so used in main-sewer construction as to form a sewer which shall be water-tight, retaining sewage and excluding subsoil water. Within the excavated trench form with concrete a bed for the brickwork. Float this bed of concrete over with a layer of Portland cement mortar not less than 1 in. in thickness. Set the invert and side-wall bricks in a single ring of 4½ in., and then give this a covering of mortar similar to the first bed over the concrete, and set the inner 4½ in. of brick upon it; the work will then be 11 in. in thickness,—9 in. of bricks, 2 in. the two beds of mortar. The upper portion of the sewer to be constructed in a similar manner if the subsoil water is liable to rise above the top of the sewer. Brick-sewers carefully constructed in the manner indicated will be water-tight.

2130.



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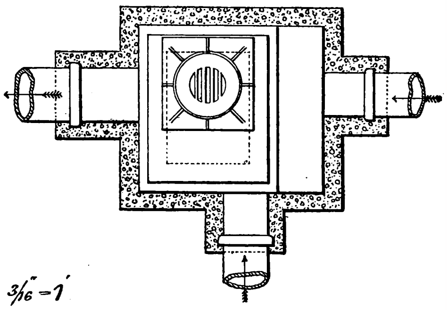

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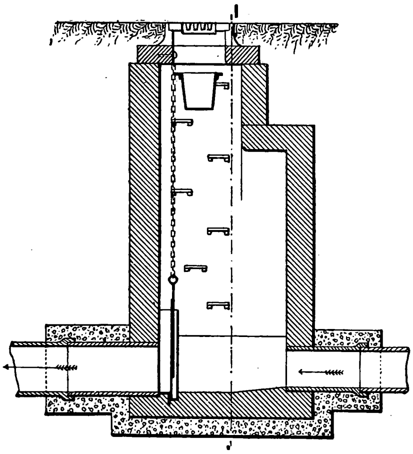

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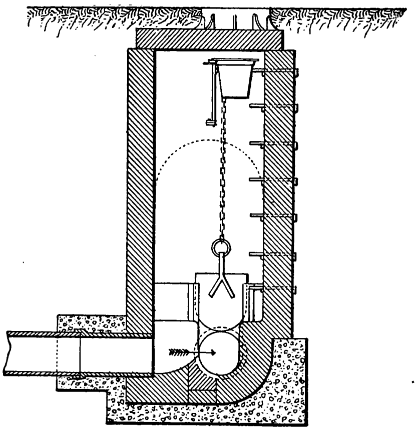


2133.

In making mortar or concrete, it will be of the utmost importance to use clean materials and to preserve them clean; the water used for wetting bricks and for mixing concrete and mortar must be free from silt. Concrete and mortar should also be used on clean surfaces.

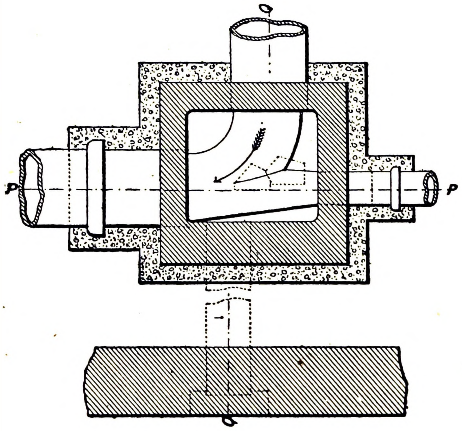
Sewers from 1 ft. to 3 ft. diameter, if required to be water-tight, may, with advantage, be constructed partly as a concrete pipe, moulded true to shape and size.

The timbering of excavations during the laying of sewers will be found described under the head of Carpentry.

When artificial foundations have to be constructed in unfavourable situations, a good foundation may often be secured by deepening the sewer trench, and filling it up to the level of the sewer; in districts in which rubble-stone or boulders are plentiful, rough rubble walling may be resorted to; a continuous wall of concrete may be constructed underneath, or piers of concrete arranged at intervals along the course of the sewer, connected by brick arches. The arches, as well as the piers may be constructed of concrete, the earth being excavated so as to form the natural centre for the concrete arch.

Figs. 2126 to Fig. 2129 are plans and sections of a manhole at the junction of two sewers entering into a pipe sewer, which is turned at a right angle, having an arrangement for flushing. Fig. 2126 is a plan at A A, Figs. 2128 and 2129 sections at D D and E E. The manhole cover is intended to act as a ventilator. The iron pail beneath the cover is to intercept any dirt which may

2134.



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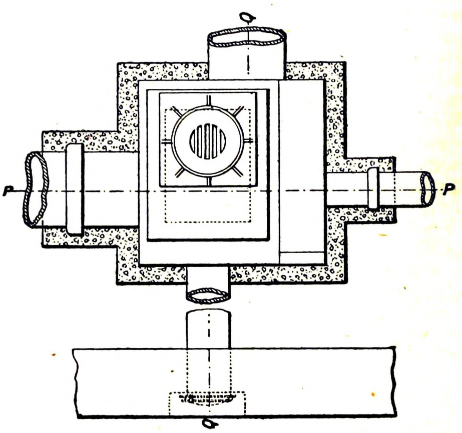
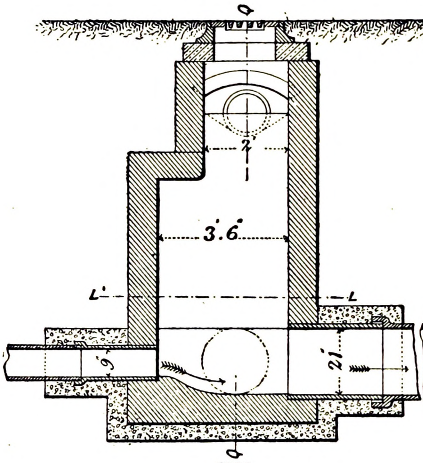
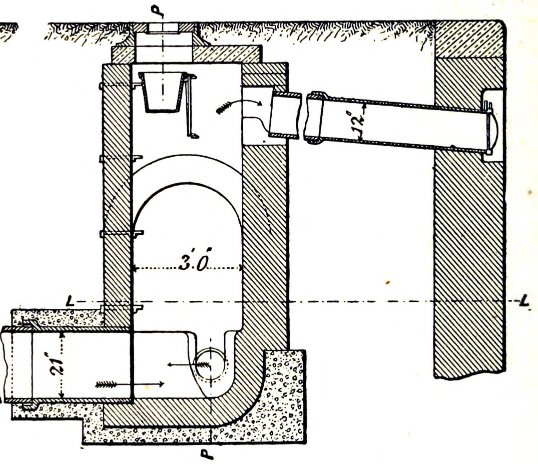


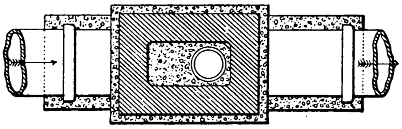

Q
2'
3.6"
L
L
9"
21"
Q

2136.


P
12"
3.0"
L
L
21"
P

2137.

2138.



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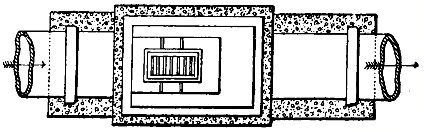

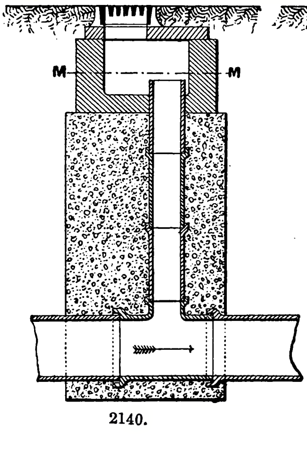

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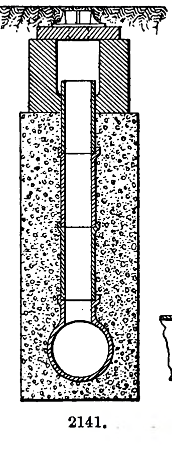

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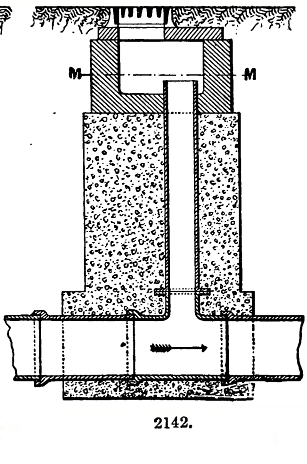

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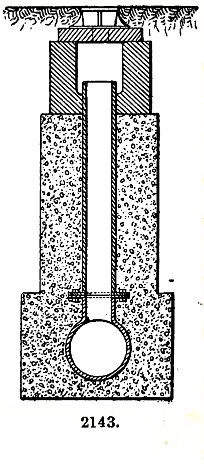
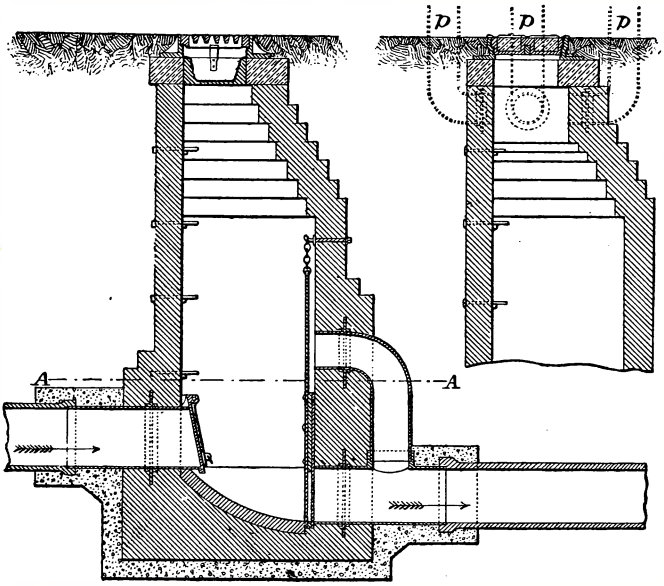


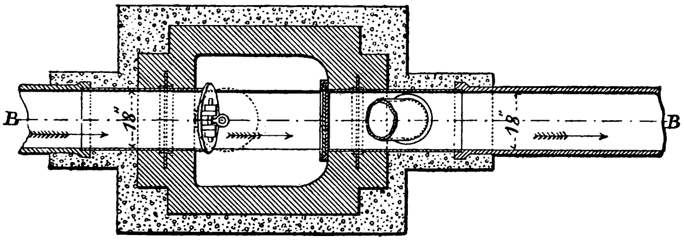
2143.

come through the ventilating openings from the street or roadway above. This pail should be made to swing round when the manhole cover is removed, to admit of entrance. The bottom of the manhole may be formed out of stone, or brick and cement, or may be moulded in Portland lime concrete, with concrete for a foundation.

Figs. 2130, 2131 are plans at B B and at top, Figs. 2132, 2133 sections at H H and I I of a manhole on pipe sewer junction, with flushing arrangements indicated. A light iron sheet, to be lowered or raised in a prepared groove, is arranged to stop back the flow of sewage or water, which is let off suddenly by drawing the sluice plate. An overflow is provided over the top of the sluice plate when this is shut down to prevent the manhole from being filled above the level of the shut-down sluice plate.

2144. 2145.





2146.

Figs. 2134, 2135 are plans at L L and at top, Figs. 2136, 2137 sections at Q Q and P P, of a manhole showing an overflow to relieve the sewer from storm water.

The head of water to be removed may vary considerably, so that the relief pipe must be placed in the manhole higher or lower, according as the house connections in the sewers will permit.

Figs. 2138, 2139 are plans at M M and at top, Figs. 2140 to 2143 sections of lamp-holes and sewer ventilating pipes, to be fixed at the upper ends of sewers and drains, as well as at intermediate points betwixt manhole and manhole.

Fig. 2144 is a section on B B, Fig. 2146, and Fig. 2146 plan at A A, of an earthenware pipe and brick sewer on a steep gradient. The end of the inflowing sewer is provided with a light flap-cover, to stop any sewer gases from below, and so compel sewer ventilation at this point. This manhole provides for flushing, Fig. 2148 being the penstock employed for this purpose in the brick sewer, Fig. 2147.

The junctions entering the manhole and the overflow pipe are of cast iron, as if there are several such manholes to be constructed this will be the best material to use.

If elevated pipes are employed for ventilation, they may be attached as at *p p*, Fig. 2145.

The brick sewer, Figs. 2147 to 2151, has well-arranged side junctions, flushing, and overflow arrangements. In other respects similar to Fig. 2144.

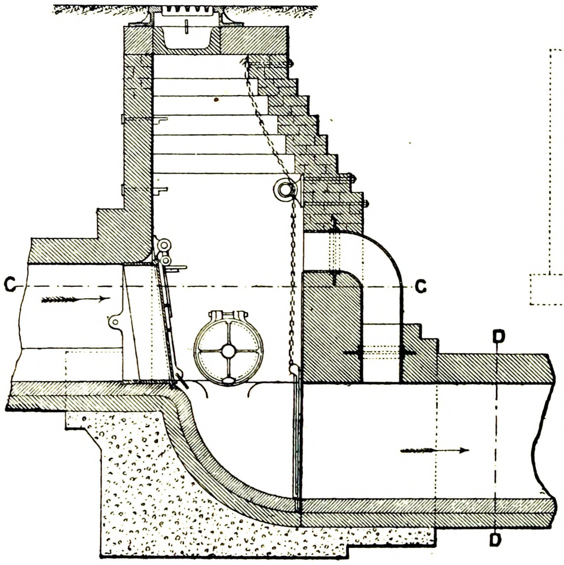
Figs. 2152 to 2154 are plan, sections, and details of manhole and brick sewer on a steep gradient, having side junctions and a screw-down sluice arrangement, Figs. 2152, 2153, for flushing with an overflow pipe.

Fig. 2155 is a section of a ramp or fall in a main sewer on a steep gradient, having an inverted syphon of cast iron, to take the ordinary or dry weather, flow of sewage, and leave the end of the main sewer closed to stop any escape of gas upwards from the sewers below.

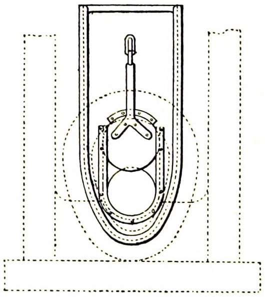
Figs. 2156, 2157 are sections of a cast-iron sewer ventilating grate.

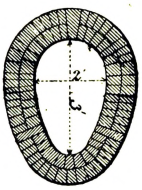
Figs. 2158 and 2161 are longitudinal sections, Figs. 2159, 2160, 2162, 2163 cross sections of two flushing chambers, to be constructed at the upper ends of sewers. The capacity of the flushing chamber will be in proportion to its cross-sectional dimensions and its length. The outlet and overflow pipes are of cast iron. The manholes to be joined on the end connecting with the sewer or drain; ventilation to be provided for at the upper end of the chamber.

2147.

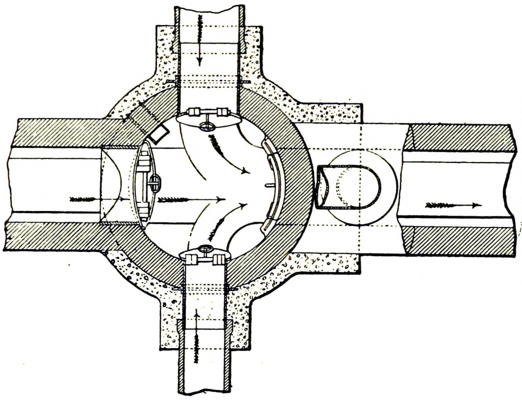


2148.

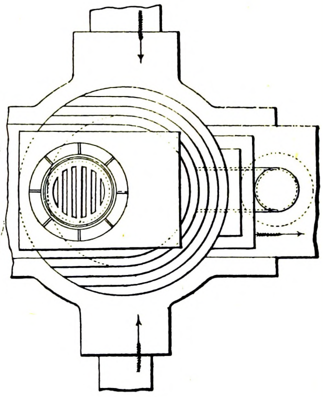




2149.



2150.



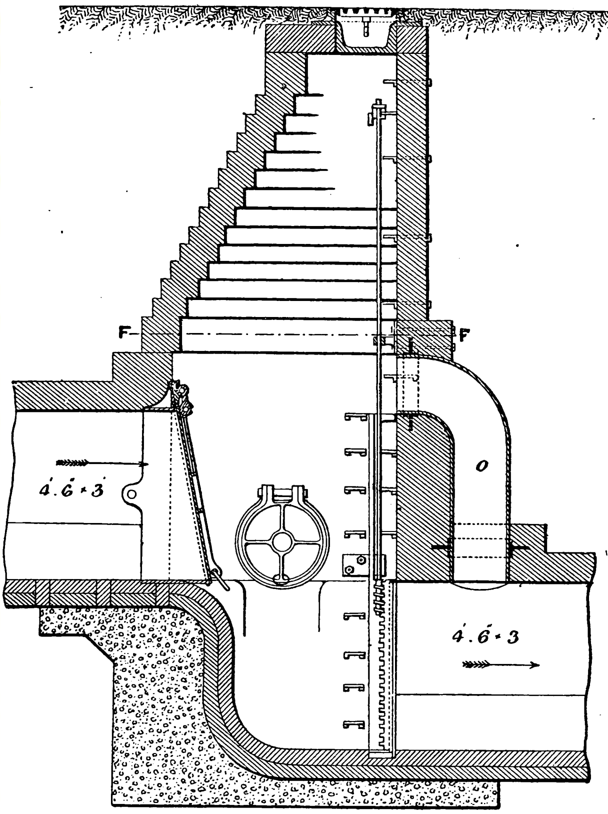
2151.

These chambers may be filled from a water main, where there is an available supply, or from any surface water, or may be filled by watercart. Care must be taken not to injure sewers and drains by overflushing. The best and safest means will be to give repeated flushings in small volumes following at short intervals, as a large body of water suddenly discharged may rupture the joints and damage the inverts, which must be avoided. The manholes and lamp-holes throughout any sewered district are intended to give facilities for sewer examination and cleansing in detail. The arrangements here shown and described are intended to be supplemental to manholes and lamp-holes on the lines of sewers.

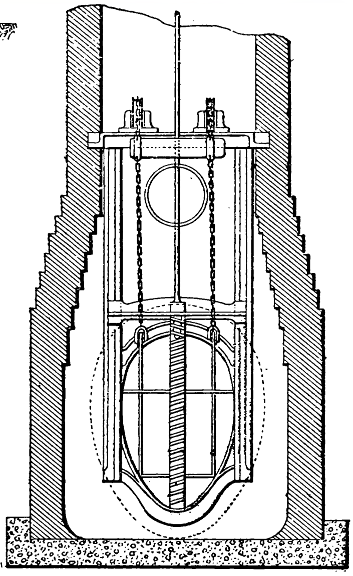
In cases in which much subsoil water occurs, it is customary to put in a line of drain pipes continuously under the brick sewer in order to convey away the subsoil water, and to give time for the brickwork to set before being exposed to its action. In other cases sump-holes are sunk outside the line of sewer, which are continuously pumped out in order to keep down the subsoil water to a lower level than the brickwork.

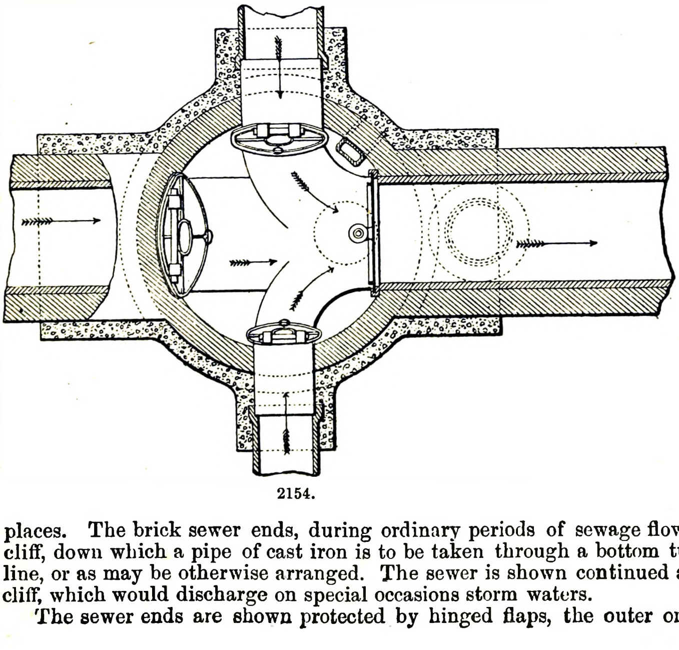
In ordinary cuttings of 20 ft. and under, in depth, when executed in good ground, and when the greatest internal dimension of the sewer does not exceed 3 ft., it is customary to build the sewers, whether circular or oval, with a $4\frac{1}{2}$-in. ring of brickwork. Sewers from 3 ft. to 6 ft. in size are usually built in 9-in. brickwork, and for greater sizes the thickness is increased accordingly. Sewers with straight sides require at least 50 per cent. greater thickness of material than curved sewers of equal dimensions.

2152.



2153.





2154.

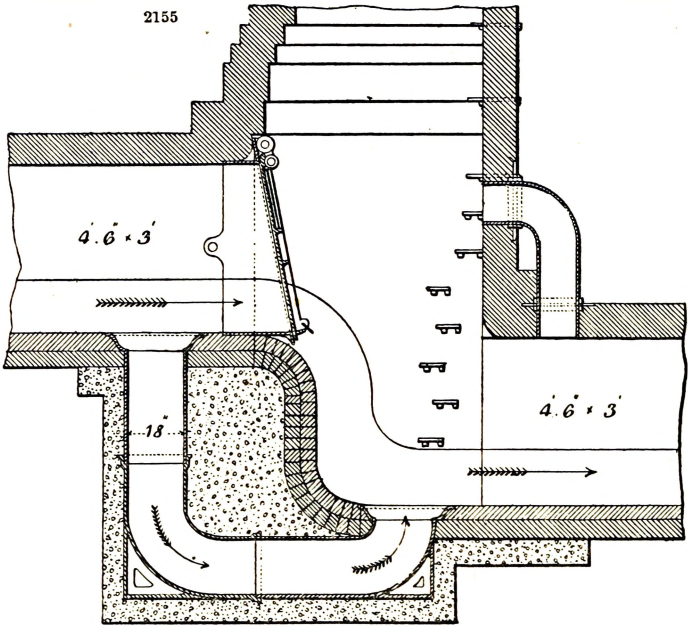
Figs. 2164, 2165, are plans, Figs. 2166 to 2168 sections, the latter at A B, of a manhole flushing chamber and apparatus on a main outlet sewer, having a flat gradient. A pipe *s* is laid beneath the sewer is to take subsoil water. The manhole cover should be a sewer ventilator, or special means for ventilation must be provided by means of a side chamber.

The flushing gate is seen in detail, open at Fig. 2167, and closed at Figs. 2166, 2168. When closed, the gate is held in place by the chain; when the sewer has been filled sufficiently to give the required flush, the chain may be slackened to allow the gate to turn over, and so liberate the accumulated water.

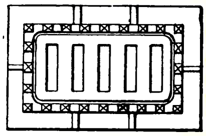
Fig. 2169 is a front view of the adit face, and Fig. 2170 a section of a main outfall sewer brought to the face of a steep sea-cliff, as at North Shields and some other places. The brick sewer ends, during ordinary periods of sewage flow, at a vertical shaft in the cliff, down which a pipe of cast iron is to be taken through a bottom tunnel-heading to low-water line, or as may be otherwise arranged. The sewer is shown continued at O to the outer face of the cliff, which would discharge on special occasions storm waters.

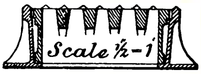
The sewer ends are shown protected by hinged flaps, the outer one to prevent the wind, the

2155



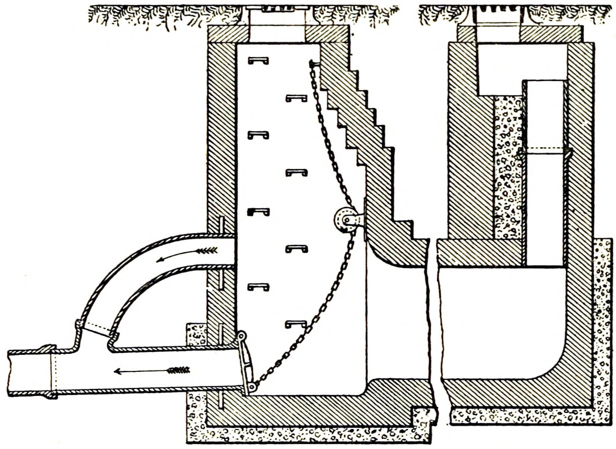
2156.



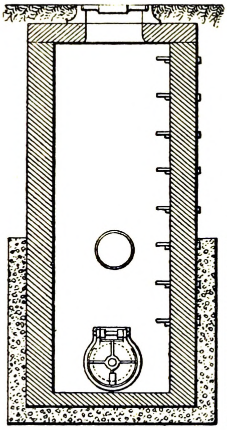


2157.

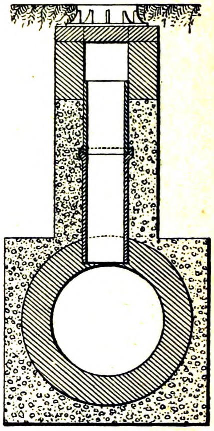
2158.



2159.



2160.



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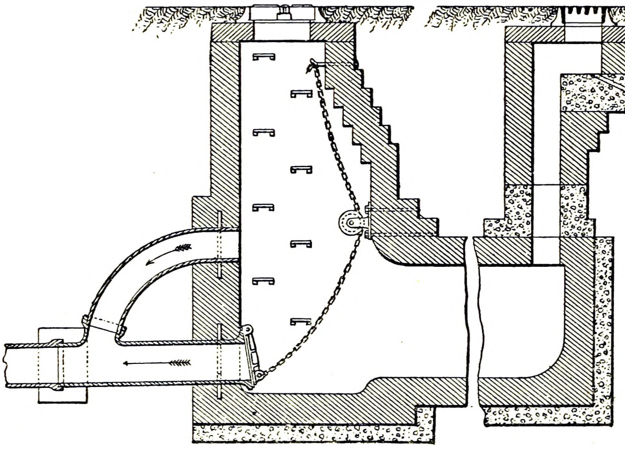
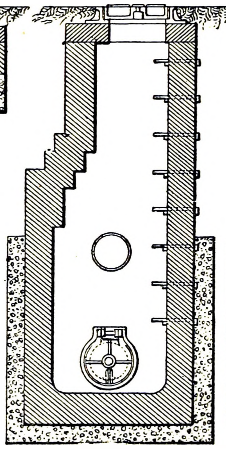
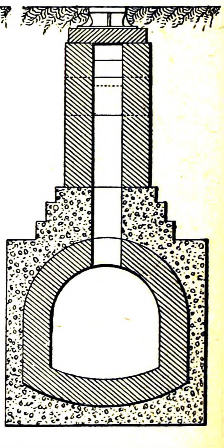


2161.



2162



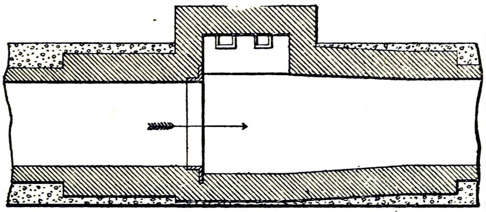
2163.

inner one also to stop wind, as well as sewage gases, from flowing back to the sewered and drained areas.

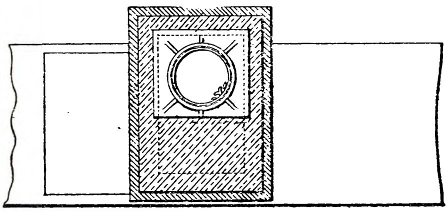
There is a manhole, the entire area being indicated as for ventilation.

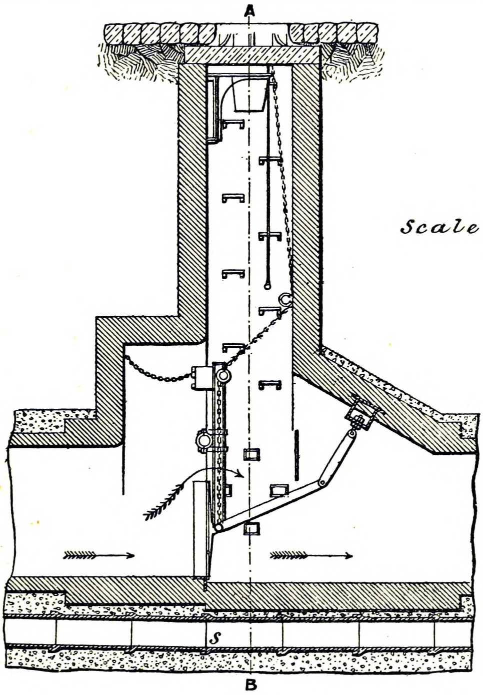
If, however, it is not convenient to ventilate at this point, the manhole may be covered, and a ventilating drain be carried from the manhole chamber to some more convenient point. The manhole must be fully ventilated. At the end of the tunnel, on the level of the beach, means of access are to be provided to enter the tunnel, and an iron ladder may be fixed in the vertical shaft to enable the engineer to examine, and if necessary, have the pipes repaired.

2164.



2165.





2166.

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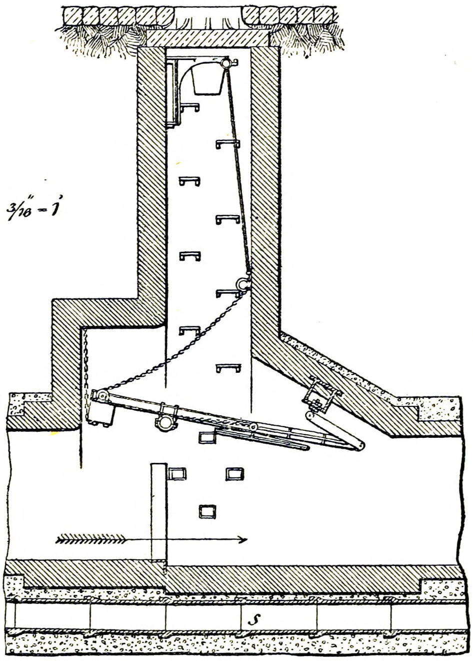


2167.

In the horizontal tunnel there is to be a relief valve *a* on the cast-iron outlet pipe, to prevent bursting when the sewer is discharging tolerably full. This relief valve will also liberate air during the rising of the tides.

A main sewer outlet to the sea, or to a tidal estuary, on a flat shore is illustrated in Figs. 2171 to 2174.

The main sewer is carried to a manhole chamber, Fig. 2171, having a flap-cover; there is a low-water outlet, and a top or high-water flood outlet. The ordinary or dry weather flow of sewage will be brought from the main sewer to the bottom of the manhole chamber by a cast-iron pipe. A manhole, with full means for ventilation, is arranged over the commencement of the low-water pipe, Figs. 2171, 2174, and the end manhole chamber must be fully ventilated, either at the cover or by ventilating pipes taken from the top of the chamber to some safe point.

The bottom pipe in the chamber, Figs. 2173, 2171, may be taken into and below low-water line; the upper or overflow pipe may be taken on to the shore below high-water line, and as far as may be found necessary. In Fig. 2171 L indicates low water, H' half-tide, and H high water.

It is intended by this arrangement to permit the tide to rise and fall within the manhole chamber in such manner as not to disturb the flow of sewage or drive back sewage gases during the rising of the tides or in rough weather.

Figs. 2175 to 2181 relate to a balanced tidal flap for a main sewer outfall. Fig. 2176 is a plan of the flap at A A, Figs. 2177, 2178 plan and elevation of bearers, Figs. 2179, 2180 side and front elevations, Fig. 2181 section. The rim of the flap, Fig. 2175, is made with a wide groove, in this is placed hemp packing covered with a band of vulcanized indiarubber, which is secured by bolts.

A proper manhole chamber would have to be constructed, similar to that in Fig. 2171, or a modification of this form, so as to protect the flap and allow it to work safely. Such an apparatus may be placed on the outlet of any sewer ending at a river margin or on the sea-shore.

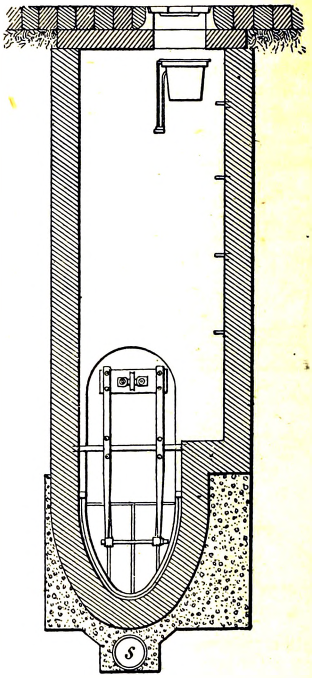
Where the character of the ground and the formation of the lines of streets will admit of the arrangement, town areas having steep gradients should be divided into zones, main intercepting sewers being formed on contour lines to receive the flow fo sewage from the upper area and prevent accumulation of sewage in the low-level system of sewers.

Manholes and lamp-holes at the junctions of common sewers, at the angles of direction, and at changes of gradient, form a fundamental feature in systematic sewerage, inasmuch as they serve the several purposes of flushing, examining, clearing, and ventilating the sewers.

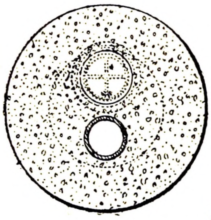
The size, form, and character of manholes vary considerably. In Figs. 2152, 2158 and 2166 will be found some approved designs.

The mode of entering a manhole is effected in different ways. If it is constructed after the manner of a vertical shaft, it may be entered at once from the centre of the street by removing the cover and using the iron steps fixed in the side as treads and holds, Figs. 2158 and 2171, while in main thoroughfares, where there is much traffic, the entrance may be more conveniently gained from the pavement or side of the street, in which case the entrances may be fitted with covers.

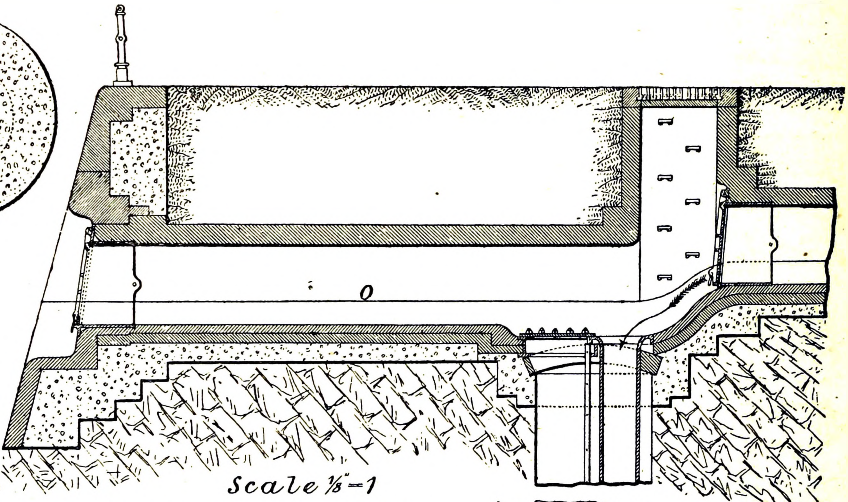
2168.

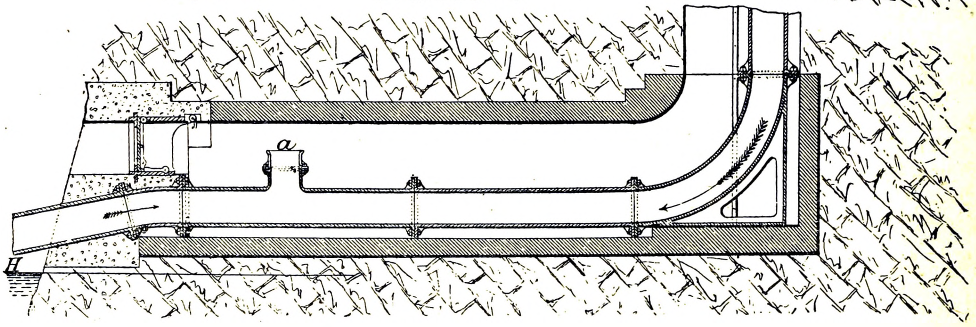


2169.



2170.





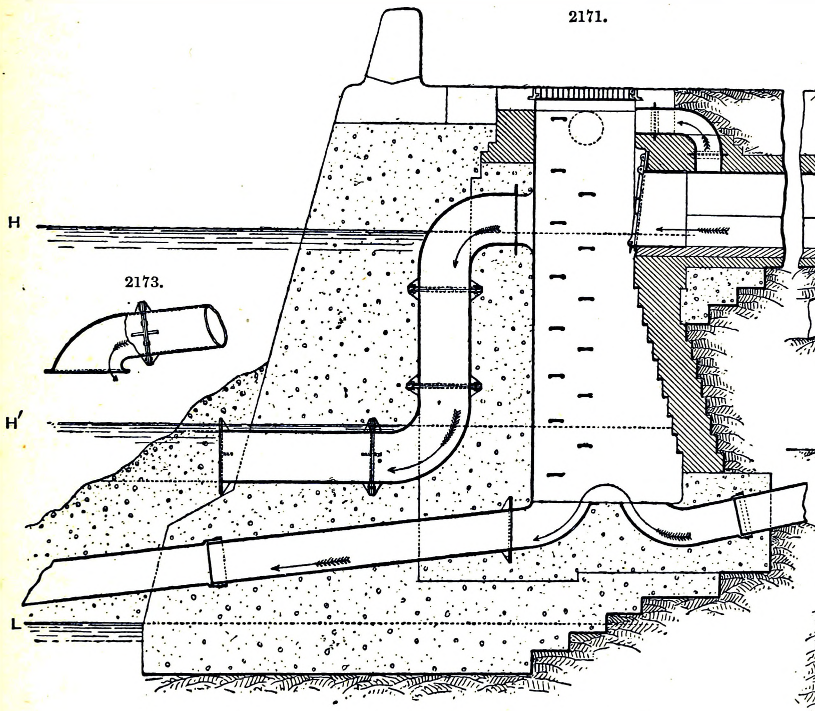
These covers are provided with an inside grating, which allows of the ventilation of the shaft by the raising of the outer lid without danger to traffic. When manholes are entered directly from the streets the covers should be formed of opened gratings to serve constantly as ventilators.

In practice the opening in the street is not found to interfere in any serious way with the public traffic.

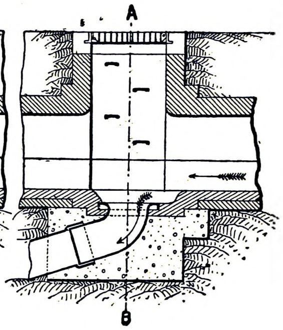
Where manholes are intended for access to doors or gates fixed in the larger sewers for the purpose of flushing them, the side entrance possesses great advantages over the vertical one, as the mode of construction enables a man very readily to bring the gates or door-valves into action.

Below the grating which forms the covering of the manhole there should be a dirt box fixed to intercept the solid matters which find their way through it, and which, if allowed to fall to the bottom of the shafts, would obstruct the flow of the sewage. The position of the dirt box in the manholes and lamp-holes is shown in Fig. 2158.

2171.



2173.



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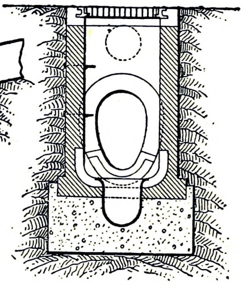
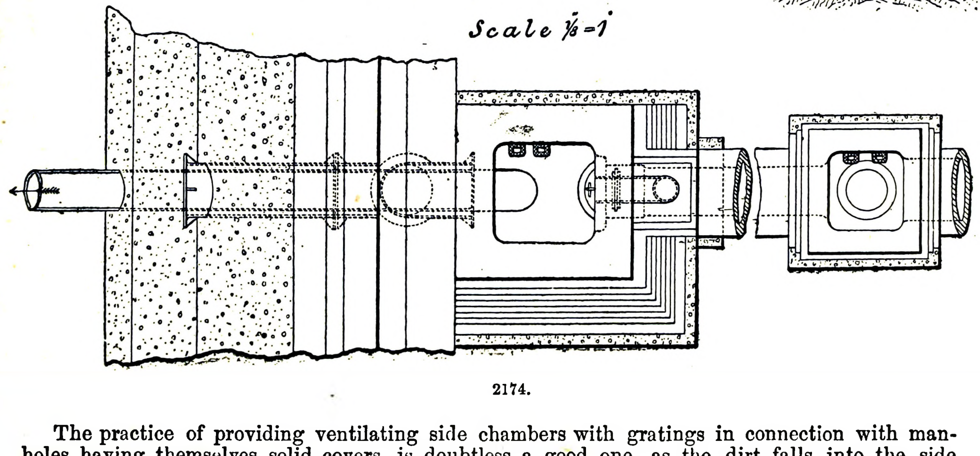




2174.

The practice of providing ventilating side chambers with gratings in connection with manholes having themselves solid covers, is doubtless a good one, as the dirt falls into the side chamber instead of the manhole.

There are few systems of sewerage in which the arrangements are such as to render flushing altogether unnecessary. Sewage may be so diluted by foreign water that it may of itself be sufficient to keep the sewers clear, but at the uppermost ends of sewers this favourable condition cannot be attained, and recourse must be had to some additional means of cleansing. At the head of all sewers there should not only be an increased fall given to the sewer, but some means should be provided of admitting water either from the public water main in a town, or from a water-cart in a village, or from a tank built purposely to collect the rainfall and retain it for use in flushing during dry weather.

Where water is scarce it may be made the most of by the use of valves or half gates in the sewers, Figs. 2129 and 2168, whereby it may be held back and let suddenly free; thus water or sewage itself in a comparatively small quantity may be made to do good service.

Half gates, Fig. 2168, may be advantageously used in manholes where the sewers are of large size, but with small sewers whole gates or valves are better. Gates should be made to shut *against* the flow and to open with it. Where the sewers are made of pipes a simple flap, Fig. 2158, arranged to open the reverse way, that is, against the flow, fixed to the outgoing pipe and made capable of being worked by a chain from the top of the manhole, may be made to do a similar duty.

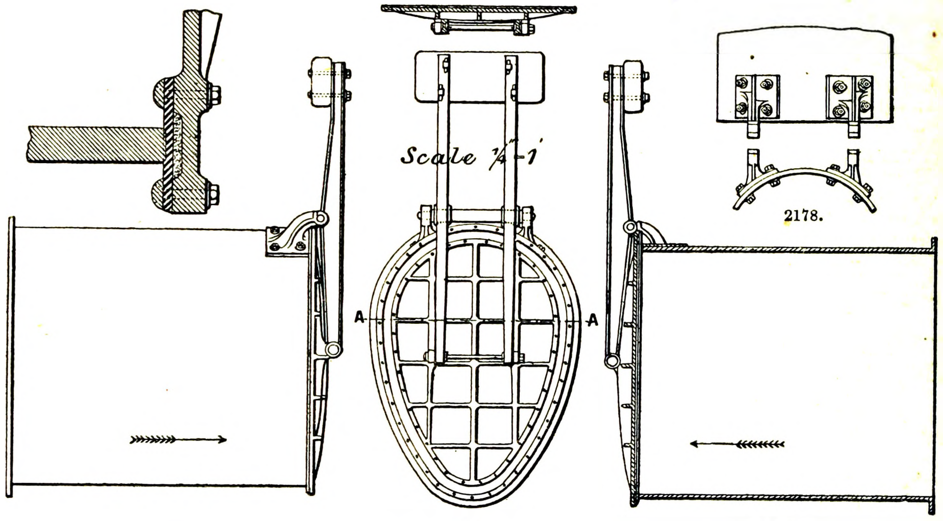
Penstocks answer very much the same purpose as flush gates, though the mechanical arrangements by which they are worked are different. The difference consists in the penstock acting vertically, and moving gradually by worm and rackwork in a chamber devoted to the purpose, while the flush gate generally works on hinges horizontally and suddenly.

The working of penstocks will be understood by an examination of Figs. 2152, 2153.

The admission of water into sewers is sometimes effected by a direct connection between the water supply of the town and certain manholes; J. Bailey Denton is of opinion that this arrangement is wrong, and carries with it an objection which must prevent its general adoption, for water is a rapid absorber of sewer gas.

Where there is a considerable quantity of water at command for flushing, the operation is better commenced from the lower ends of the sewers, but where, on the contrary, the water is scarce the flushing liquid must be made to do its full amount of duty, by detention at several manholes in succession from the head downwards.

2175. 2176. 2177.



2178.

2179. 2180. 2181.

The gullies now in use differ in their distinguishing features in two particulars, the one being a comparatively shallow receptacle, covered by a grating, through which the water and the road detritus pass together into the sewer or surface drain, the other consisting of a catch-pit in which the detritus deposits itself while the liquid alone passes onwards. The latter description should be invariably adopted when the gullies are connected with the sewers.

The depth of the gully catch-pit for the interception of the solid matters will depend upon the nature of the roadway or street, as well as upon the inclination of the surface. For paved streets and regular surfaces, for instance, it will not be necessary to make so great a provision as in cases where the streets are macadamized, and where the inclinations are steep. In London the sizes of the gullies vary considerably, some of them holding 40 and others as much as 90 cubic feet of deposit. The degree of attention given or rather required to be given by local authorities to the emptying of catch-pit gullies may influence the size of the receptacles, for the more frequently they are emptied the less, of course, need be their capacity. They will generally be larger in rural towns with macadamized roads than in towns with paved streets.

Where gullies connected with sewers exist by the side of footpaths in much frequented streets, and in yards and courts, special care should be taken to prevent the escape of the gases of the sewer, by the most efficient means of trapping. This object is effected in most of the gullies now in use by the common dip arrangement; in others by bends or elbows in the pipe connecting them with the sewer; and in others by self-acting balance metal valves. Those gullies in which the water itself is used as a means of trapping are better than those provided with metal balance valves. The latter are sometimes used where the road detritus and other solid matters are admitted into the sewer. They are subject to derangement by a portion of the solid matter resting on the valve and preventing its closing perfectly, in which case the gases which the valve ought to exclude escape into the street or yard. But even if the valve shuts closely when not in action, directly it is opened by the force of the descending water and its solid matters, the gases that have collected beneath it will rise upwards and escape. The disadvantage of using water as a means of trapping consists in the fact that the water is apt to be evaporated, and it is occasionally necessary to fill the receptacles with water by hose or water-carts.

A gully is an opening provided for receiving surface water or waste. A trap is a barrier placed between the sewer and the external air. Gullies and traps are closely related, for although we may have traps without gullies, no modern gully can be considered complete without a trap, and the trap and the gully are often so constructed as to be inseparable. All gullies and traps are now formed either on the water trap or valve trap principle, or by a combination of both. Water traps usually partake of the character of an inverted syphon, and are liable to become untrapped from running full bore and acting as a syphon proper, in which case the induced current tends to create a vacuum below the trap; air follows the flowing water, and drives or sucks out sufficient water from the trap to leave the aperture unsealed. The remedy for this defect, which is constantly occurring in the case of small pipes, is to provide free ventilation below the trap, to make the trap of rather larger bore than the pipe communicating with it, and to cut off all direct communication with the drains. Another, and not uncommon, cause of the failure of a trap is the entry of some substance which will act as a syphon, and drain all the water out of the trap, leaving it unsealed. For example, the traps of sinks are very apt to become untrapped in consequence of a thread or two of a dishcloth entering and hanging partly in the water of the trap and partly down the drain, when it acts as a syphon and drains it. The only remedy for this defect is the exercise of constant surveillance. Traps are also particularly liable to fail from the evaporation of the water which forms the seal. Valve traps are more defective than water traps.

Mechanical or balance traps have been used both in soil pipes and in connection with water-closets and gullies.

Storm overflows serve as safety valves to the sewerage system, and should be placed in such positions that a direct communication with the sea, river, or watercourse forming the natural outfall of the district may be readily gained. The precise shape they should take and the mode of connecting them with the sewers will be determined by local features. Figs. 2170, 2171 exhibit overflows, one into a river and the other into the sea.

Self-acting valves or flaps, of which Figs. 2170, 2180 are examples, are also necessary provisions in most sewerage systems. Such contrivances are undoubtedly necessary wherever the sewers discharge into the sea, or into a tidal river below high-water level, not only to prevent the inflow of the sea-water, but to keep out the wind and prevent the driving back of the sewer gases into the streets and houses in times of storms. Flaps are sometimes advantageously affixed to a sewer as it passes through a manhole, in order to prevent the onward passage of sewer gas generated below. By appending light flaps in manholes built in sewers with steep inclinations, the escape of effluvium may be so evenly distributed as to avoid objection. Flaps are sometimes affixed to the junction of minor or private communicating pipe sewers with brick sewers, and are extremely useful, if well executed.

Denton observes that all tidal valves should be truly balanced and self-acting, so as to yield to the slightest pressure. They should be close fitting, to exclude the outer water, and also, when facing the sea, be protected from the direct action of the waves, as the sudden motion of the valve backwards and forwards gives impulse to the sewer air, and causes it to force its way upwards into houses in defiance of traps and syphons.

In every system of sewers, and even in the drains of blocks of houses, public buildings, and large private houses, it will be advisable to prevent the accumulation of sewage gases. The manhole chamber arrangements due to Rawlinson, Fig. 2152, are designed to show how by ramps or tumbling bays, the rush of sewage down steep gradients may be arrested, and the upflow of sewage gases be stopped by the flap covers on the ends of sewers and drains. This form of arrangement may be adapted to sewers and drains of all forms and dimensions, as also to closet pipes, pipes from house sinks, and overflows from house cisterns. A main point is that sewers and drains should not be continuous flues up which sewage gases can flow, accumulate, and concentrate, but all sewers and drains should have points of interception and of ventilation calculated to subdivide and liberate the fresh gases at numerous safe points, externally. That is, no sewer or drain must, under any conditions, form one continuous tube or flue; neither should sewers nor drains traverse the basements of buildings, public or private, but be outside the main walls.

It is to be regretted that the several means adopted for the ventilation of sewers have failed in the attainment of a satisfactory result. It is hardly necessary to say that wherever sewer gases escape into dwellings they have an injurious, if not a dangerous, effect, and that everything that can be done should be effected to prevent their entry. Uniform aëration seems the only means of ventilation which is at all of service.

Much has been said in favour of the use of charcoal to purify effluvium; but the efficacy of charcoal depends so much upon its being kept free from dust and in a dry condition, that its purifying functions, when used in connection with sewers, soon cease to have any effect. Where, therefore, aëration can be gained by manhole and lamp-hole openings at regular and frequent intervals throughout the sewerage system, with occasional shafts for ventilation only, aided by private ventilating outlets above dwellings, recourse to charcoal is undesirable.

The following remarks upon the matter are due to Waring;—

"The principle of the ventilation of a sewer is practically the same as that adopted by builders for the prevention of dry rot. The fungi which cause this rot in timber cannot produce their germs in a current of air, and if a sufficient number of ventilating openings are made, communicating with each other, the action of the wind from one side or the other will cause a sufficient current. So in a sewer a continuous movement of the air in one direction or the other carries away and dilutes sewer gases, and if they contain germs of organic disease capable of infecting the human blood, these are believed to be destroyed by oxidation or otherwise.

"A safe sewer always has a current of air passing through it, and if it contains sewage matters at all, these also must be in constant motion. On this incessant movement of the air and the liquid must we rely for our only security. A solution of sugar in water, remaining stagnant, and protected from a free circulation of air, will enter into a vinous fermentation. If well ventilated and agitated, no such fermentation takes place. It is asserted that the excrement of a typhoid patient, continually agitated in contact with fresh air and a fair admixture of water, passes through a series of complete chemical changes, with no injurious product; but if allowed to remain stagnant, if not freely exposed to the air, or if it gain access to human circulation before a certain oxidation, it will, like a ferment, reproduce itself, and give rise to the conditions under which it was itself produced. Motion and aëration are therefore needed to prevent infection, which is sure to be generated when typhoid evacuations are confined and stagnant. Unventilated and badly constructed sewers are sure agents for the propagation of the disease when once it has taken root.

"The resulting gases of sewer decomposition are the vehicle or medium for the conveyance of infection, and from their lightness they give rise to a rapid diffusion, owing to the eagerness with which they seek means of escape at the higher parts of the sewer system, that is, in house drains, soil pipes, and connections. It may not be possible entirely to prevent the development of the poison in even the best arranged sewer, but it is possible, by a free admission of air, to supply the oxygen which will take away its sting and render it harmless. Sewers which have large and frequent openings at the street surface, and through which the liquid contents have a constant flow, may give forth offensive smells, but, if they have proper attention, sanitary evils do not often result.

"Sewer gas, when largely diluted on its escape, at frequent intervals, into the air of the street, is probably nearly or quite innoxious, but when it forces its way into the limited atmosphere of a closed living-room, the poison, or the germs of disease accompanying it, may easily work their fatal effects.

"Sulphuretted hydrogen is found in all sewers in which the sewage itself or the mucous matters adhering to the pipe assume a certain degree of putridity in the absence of a sufficient supply of fresh air. This gas is extremely poisonous; so much so that one part of the gas to two hundred and fifty parts of atmospheric air will kill a horse. At one-half this intensity it will kill a dog. A rabbit was killed by having its body immersed in a bag of it, although its head was not inclosed, and it could breathe pure air freely.

"One of the most frequent sources of pressure upon the air within a sewer is the increase of temperature arising from the hot water escaping from kitchens and baths. The repeated expansions and contractions caused by the admission of hot and cold water produce a constant effect on all water traps connected with unventilated sewers. With ventilation, the breathing in and out, as the air of the sewer contracts or expands, does not affect the water traps, because an easier passage is found through the ventilators.

"The constantly changing volume of water in many sewers, as has been before stated, exerts a powerful influence on the confined air. As the water rises it reduces the air space, and if it reduces this to one-half, it brings to bear upon the air a pressure equal to a column of water 34 ft. in height, and this pressure is relieved by a forcing out of air through the most available channel—the channel where there is the least resistance; if there is no other vent, a sufficient number of water traps must be forced to allow the pressure to become reduced. It being reduced, and the water falling again to a lower level, a vacuum is created which must be supplied by air forcing the traps in a reverse direction, and in either case the forced trap may remain open for the free passage of foul air until another use fills it with water. In the ebb and flow, too, a part of the perimeter of the sewer is made alternately wet and dry, with an accompanying production of vapour and gas.

"As the chief domestic use of sewers is between morning and noon, and as at this time the most hot water passes into them, the pressure on the air in the sewer is during this period increased both by an elevation of the temperature and by a reduction of the air space. Then, from about noon until the next morning the quantity of the flow decreases, the air space increases, the temperature falls, and more air must be admitted to supply the partial vacuum created. Such fluctuations are constantly occurring, accompanied with a drawing in and forcing out of air, for which ample passage must be made, independently of the water traps of houses, or sewer gas will surely enter them. Where proper air vents are provided, this ebb and flow of the sewer may be increased, with great advantage in the matter of ventilation, by artificial flushing arrangements, which will allow the water to be dammed back and released at frequent intervals."

The success of the drainage will depend both upon the position and the number of outfalls to be brought into operation in a district. As a rule it is usual, in constructing sewers, to lay them in the direction of the natural falls of the district, consequently the outfalls of sewers are almost invariably found to be located in the valley of a river or stream which naturally provides for the drainage. But as it is advisable that the sewage should never be allowed to intermix with the water of the country, provision must be made for either purifying the sewage before passing it into the fresh-water streams, or, as in the case of sea-coast towns, to lead to such a point as not to become the cause of offence. In inland towns there are chemical or mechanical systems for precipitating or deodorizing the sewage. The plan that has hitherto proved most successful in purifying the sewage of an inland town is that of utilizing it in its fresh state on properly prepared land. In sea-coast towns it will generally be found most economical to carry the sewage directly out to sea; but in some cases, as a matter of precaution, the sewage may be required to be filtered, or otherwise treated, before being discharged into the sea, as prevailing winds may blow floating-matter on to the shore. In some towns, a system of interception hereafter referred to, with two or more outfalls, may be advantageously introduced in order to diminish the cost of the system of sewers, and establish the economic disposal of the sewage.

There are two principal ways in which excremental matter may be dealt with, the dry system, and carriage by water. The first is the most rational, as well as the most consistent with public health and with national prosperity. The weak part of this system, however, is that, while it disposes of excreta, it leaves untouched all the other sewage, which would still require to be removed by water carriage, and be purified, of course, before passing into a river in the same way as if it contained the whole excreta. While, therefore, upon economical and sanitary grounds, water-closets, especially in houses of the smaller sort, and in public works, jails, railway stations, should, as far as possible, be replaced by an efficient dry system, the adoption of this course will not very much lessen the amount of sewage to be dealt with, or render its purification less imperative.

When water carriage is used, the following methods may be employed for the disposal of the sewage:—

Running it into the sea, or into a tidal river, under conditions that will prevent its return, irrigation, intermittent filtration, purification by precipitation, lime, sulphate of alumina, or by the A B C system.

The dry method includes pan closets, earth closets, Goux system, Stanford's system, Carbon Fertilizer Co., Liernur's Pneumatic system.

These various methods will be briefly considered in their relation to the requirements of a large city.

Water irrigation carried on in warm weather is exceedingly unhealthy; in fact, a kind of fen is made of the large area of land the water is run over. Where the water is foul, that is, not purified by precipitation, the odour, particularly at night, and upon still damp evenings in autumn, is very sickly, and that in all these cases a great deal of disease prevails. With regard to sewage irrigation, the sewage forms a deposit on the surface of the ground; that deposit forms a cake of organic matter, and when it is in a damp state, as it usually is, gives off in warm weather a most odious stench.

It is right to add, that at many places no evil effects have been traced to the influence of the farms irrigated by their sewage, and that many of the most reliable authorities confidently affirm that sewage farming is not attended with injurious effects upon health.

Crookes makes the following observation on sewage farming;—The finest manurial qualities are possessed by the constituents of sewage, but the irrigationist is so wasteful in their application that, in the majority of cases, there ensues not a healthy crop, but a mass of overgrown rank grass material of no more nutritive value than weeds; for it must be distinctly remembered that this is not a question of manuring with sewage when necessary, but the compulsory application of enormous quantities, in season and out of season.

The quantity of land that appears to be necessary, under favourable circumstances is about an acre to each 100 of population. There is another aspect of the irrigation question, that on a skilfully conducted sewage farm, as contrasted with an ordinary agricultural farm, the cost of labour amounts to three or four times the sum usually expended an acre, while the produce is, at the same time, greatly augmented. The question arises whether, if it costs a town, say 10,000*l.* per annum to purify its sewage by chemical treatment, and then to run it into a river or into the sea, and a like sum is lost in the working of an irrigation farm, is there not the manifest advantage gained to the country by a large expenditure in the wages of labour, and the greatly increased supply of food for man and beast? Given, therefore, a sufficient quantity of land at a reasonable distance from the town, and free from a resident population; and looking to the superior effluent produced, irrigation presents the most perfect means for the disposal and purification of sewage; and it is consistent with the facts that, if the levels of the land are suitable for the reception and distribution of the sewage without pumping, and if the land is obtainable at an ordinary agricultural value, a sewage farm might be made to yield a profit.

Purification by chemical treatment has been much misunderstood, and consequently discredited. Because it has not done all that has been claimed for it, some have been inclined to regard it as a failure, and unworthy of consideration. Several processes have been advocated for purifying sewage by precipitation, and at the same time manufacturing from the sludge obtained a manure which will be saleable at a considerable price, under the name of native guano, or some other high-sounding title. The purification of the sewage is possible, and has been carried out successfully, but the sale of the so-called manure, except in insignificant quantities, appears to have failed of accomplishment. And this is not to be wondered at; for the precipitant, whatever it may be, while it removes the solid matter of the sewage, together with the phosphoric acid, leaves in the effluent water all, or nearly all, the ammonia and all the potash salts, these constituting by far the most valuable part of the sewage. All hope of making anything of the precipitate or sludge should therefore be abandoned; but that is no reason why the process should not be adopted for the purification of sewage.

The matters removed by lime and by alumina, which are practically the only precipitants that have hitherto been employed, are solid matters. Phosphoric acid, fatty acids of soap, nitrogenous organic matters, vegetable colouring matters, magnesia.

The nitrogenous compounds and the ammonia in the effluent soon become oxidized, less rapidly in salt than fresh water; and the oxidation is greatly facilitated by passing the purified sewage through a porous material, with free exposure to the air.

Of all the substances proposed for precipitation, the one that appears to be most capable of general application is lime. It can be had everywhere, is cheap, and effects a sufficient purification to enable the effluent to be passed into a non-potable running stream or tidal river, especially if the precipitation is supplemented by filtration through some form of charcoal, or by running it over a limited extent of suitable land thoroughly drained. It has been objected to the lime process that the effluent soon decomposes, while that from other precipitants, being neutral or faintly acid resists putrefaction for a much longer time. But the lime effluent also readily oxidizes, and as the organic matter in the purified sewage must be oxidized, the sooner this is accomplished the less likely is it to produce injurious consequences.

Under any system of precipitation, it is most important that the sludge should not remain long in the bottom of the settling tanks; whenever it is permitted to accumulate for a week or two it ferments, throws up bubbles of the gaseous products of decomposition, and serves to render the effluent offensive.

Wm. Shelford, in vol. xlv. of the Minutes Inst. C.E., gives an interesting account of some experiments with Campbell's process. This consists in adding phosphate of lime in a soluble state to the sewage, and in precipitating it, after sufficient admixture, by a further addition of lime.

The plant consisted of an ordinary hand pump for raising the sewage; two mixers worked by a continuous shaft from the hand pump, so arranged as to prevent the subsidence of the chemicals in the water with which they were mixed, and at the same time to bale the due proportion of each into the sewage; a mixing trough for effecting the admixture of the chemicals with the sewage; a series of six concrete tanks for the precipitation; a series of filter beds for partly drying the sludge; a Milburn's drying machine for completing the dried manure.

The two mixtures were an adaptation of the water-wheels employed in Alpine rivers for raising water by buckets attached to their rims. Each of them consisted of a wheel which revolved in a suitable vessel containing the chemicals, diluted with water, at a sufficient velocity to prevent their subsidence, and at the same time by means of cups attached to the ends of the spokes the right quantity of each chemical was raised and thrown into the trough containing the sewage.

The mixing trough, made like a "salmon ladder," was first applied by Shelford to these works, and was found to be so convenient and economical, that he afterwards used it elsewhere on a large scale.

The tanks were arranged so as to be capable of use for the treatment of the sewage either during its continuous flow through them, or by intermittent flow into each, and then allowing the sewage to remain at rest during precipitation, but without stopping its flow into the works. Each tank was a cube of 4 ft., and held about 415 gallons. The series of six held 2500 gallons, or twelve hours' flow of sewage. When worked by continuous flow, the two first tanks are used alternately and receive most of the precipitate. From these the flow of the sewage is directed through the remaining four, but any one of them can be emptied and cleaned by shutting it off with sluice boards. When worked by intermittent flow, the tanks are filled, and after a proper lapse of time for the deposit are cleaned in succession.

The filter beds for partly drying the sludge were of the commonest description.

Milburn and Co.'s machine, Figs. 2182 to 2186, for drying sludge, was also adopted, and gave excellent results.

It consists of a floor or bed formed of cast-iron plates, on to which the wet sewage is fed. Beneath this floor, at the feeding end, is the furnace which is covered in with a firebrick arch, terminating in a double bridge. In the bridge are openings through which the heated products of combustion pass away under the iron drying floor. The brickwork furnace crown prevents the floor being overheated at that point which would cause damage to the manure. The heated air from the furnace after passing under the floor returns over it, through the drying chamber, which forms a flue, the hot air carrying with it the vapours arising from the drying process, which pass away together through a chimney over the feeding end of the machine. A cast-iron frame is placed over the drying bed, and extends nearly the whole length of the floor. This frame is movable, and it carries a series of transverse bars which form scrapers, Figs. 2182 to 2184, the edges of which rest upon the floor. The frame also carries a series of slowly revolving agitators or rakes, which are placed immediately between the scrapers, and which move to and fro with the frame. The duty of these agitators is to stir and break the manure up at the wet end and along the bed until it is dry, when their action causes the manure to become pulverized, until at the exit end it is in a finely powdered condition. On the top of the frame are brackets arranged so as to form vertical slots in which crank pins work, the cranks being attached to gearing at each side of the machine, and the whole being so arranged as to revolve together, as in Fig. 2264. The vertical slots are equal to the full length of the stroke of the crank, so that at each stroke the frame is moved slowly to and fro. The transverse scrapers sweep the entire surface of the bed, and by keeping the manure in constant motion prevent its caking on the iron plates.

On the top of each of the slots, or crank-pin guides, is mounted a movable stop block, which is adjustable by means of a screw, and by which the length of the slot is increased or reduced as required. According as the slot is longer or shorter, so is the frame lifted to a greater or less height at its backward stroke when the scrapers and stirrers pass over a portion of the manure. At the return stroke each scraper passes on a portion to the next scraper, and thus the manure gradually travels the whole length of the plates, until from a wet coherent mass at the feeding end it becomes a dry powder at the delivery end of the apparatus where it makes its exit. The drying floor is covered in with iron plates, which are carried on the top of the frame, thus inclosing the manure whilst being dried, and forming the return flue already alluded to. If it should be found desirable to destroy the noxious gases, that is effected by means of a special furnace, through which they are forced, and in which they are entirely decomposed.

Experiments were made to determine the best proportion of chemicals to be used, and it was found to produce a good effluent water, was a dose of 10 lb. of superphosphate and 3 lb. of lime, or a total of 13 lb. of chemicals each 1000 gallons. The effluent water as it left the works was either neutral or gave a slight alkaline reaction, and was more suitable for irrigation purposes than raw sewage.

The precipitate, or sludge, when run upon the filters, contained 90 per cent. of water, and was about 1 ft. deep. The heavier matter at once subsided, and left the water on the top; but in consequence of the absence of clay, and the porous condition of the sludge, the water percolated through both it and the filter, until a comparatively solid stratum of sludge, of the consistency of mortar, was left. The filters were found to work best when the partially dried sludge did not exceed 3 in. in thickness. The sludge when shovelled off the filters contained 80 per cent. of moisture, and was accumulated for two or three weeks in that state without being at all offensive until a sufficient quantity had been prepared for Milburn's machine. The sludge from Campbell's

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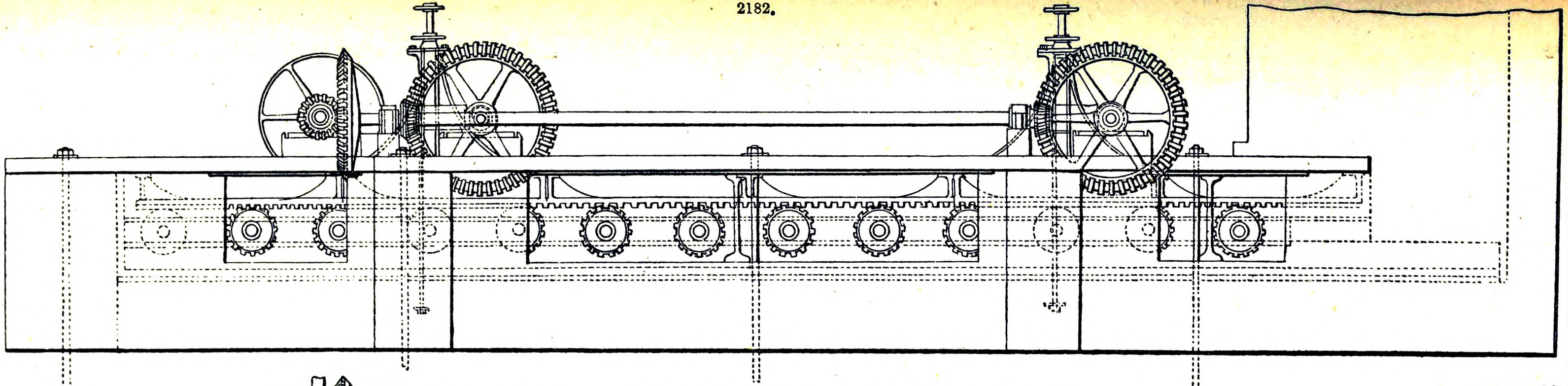

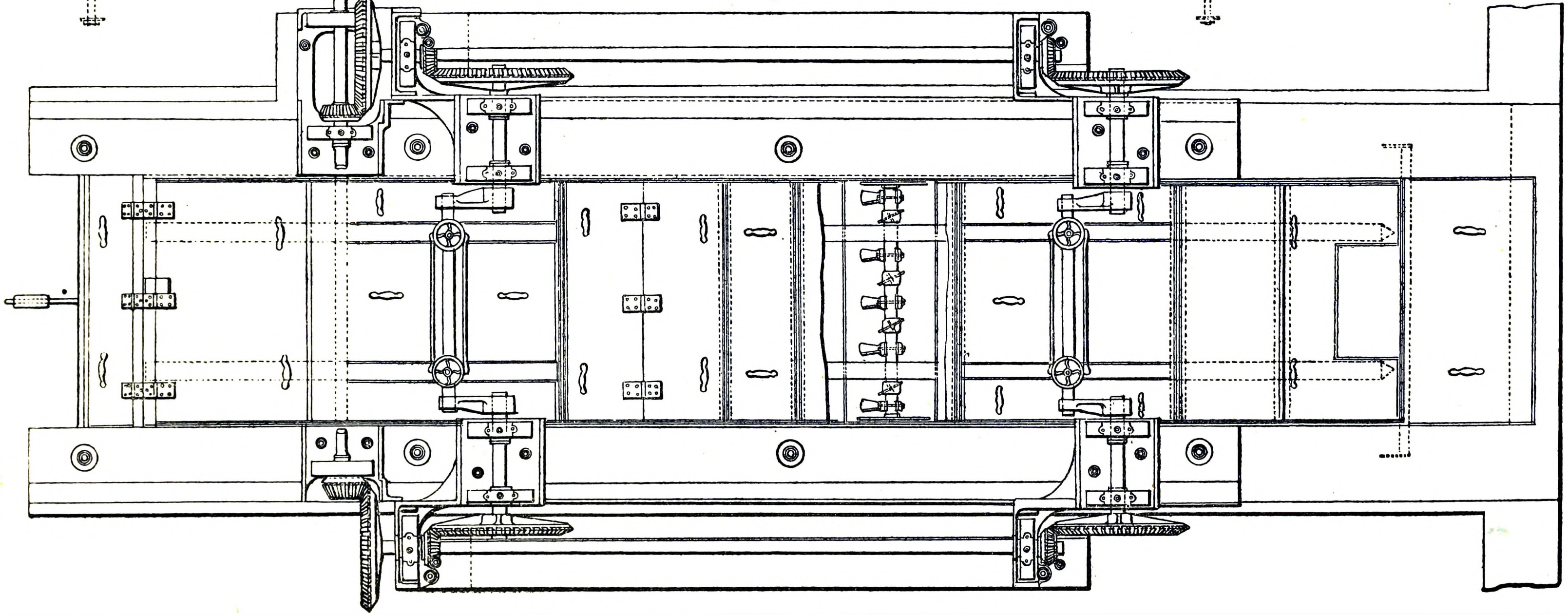

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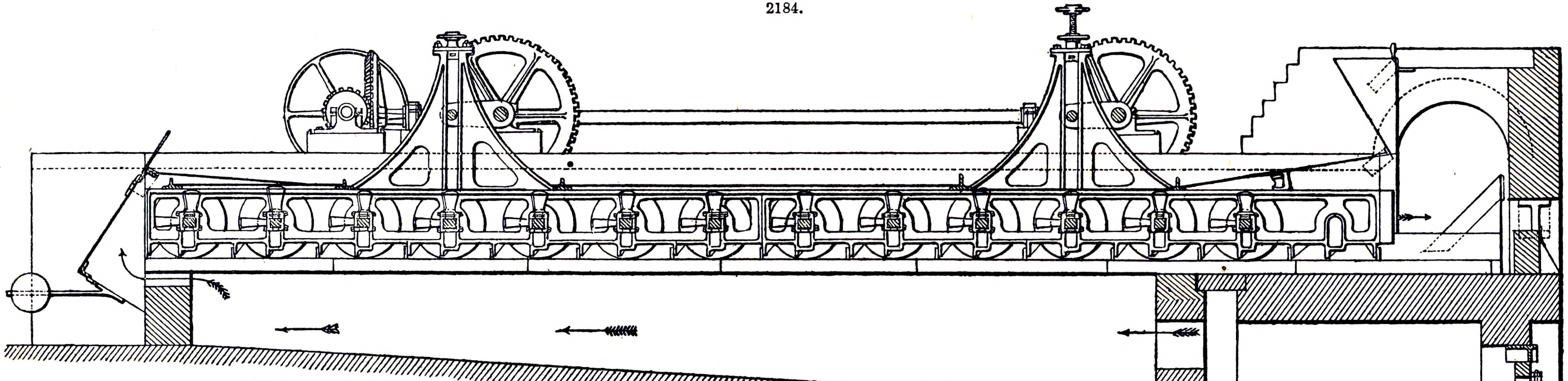

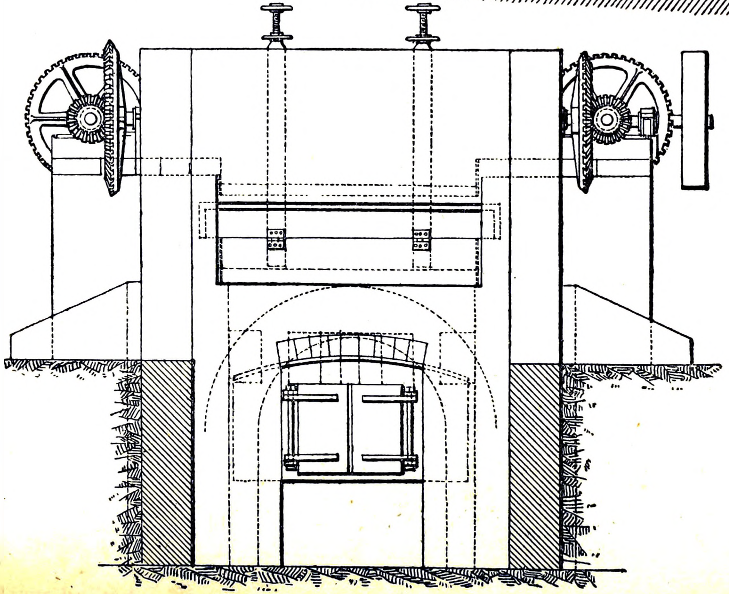

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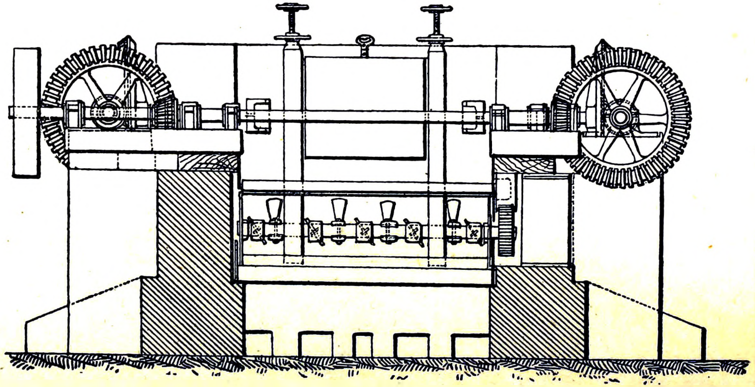
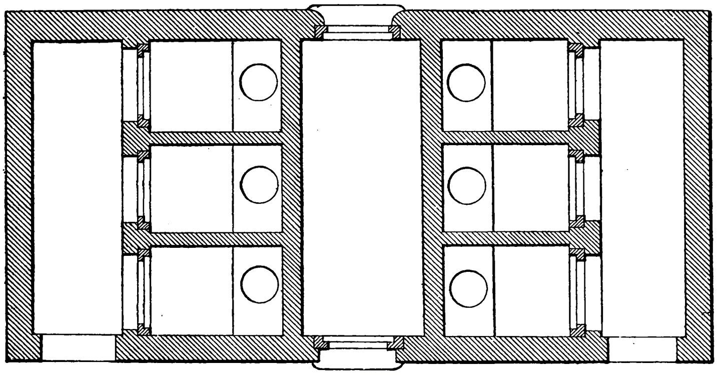


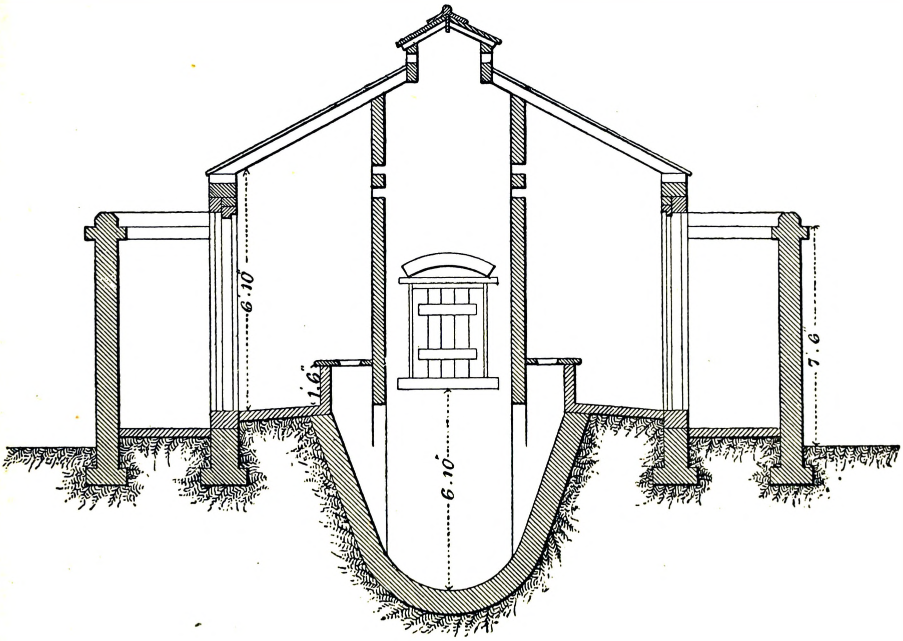
2186.

process appears adapted for drying by filtration, a circumstance due to the absence of clay in the precipitants employed, to the large proportion of chemicals compared with the sludge, and to their porous condition. Its importance can hardly be overrated, inasmuch as it solves the difficulty of drying, which has been more troublesome than any other mechanical question. Experiments and analyses showed, moreover, that the value of the sludge was not affected by its filtration, whilst the quantity of moisture abstracted by it was at least one-half, even after the sludge had been brought to much greater consistency by draining off the water as it collected upon the surface.

The value of the manure corrected to contain 18 per cent. of sand and 10 per cent. of moisture, thus showed a margin of 5*s.* a ton after payment of expenses. The worst result showed that the manure was worth about sufficient to pay the cost of the chemicals and leave a margin.

2187.





2188.

Precipitation by a solution of sulphate of alumina mixed with the sewage, and afterwards neutralized by lime, has the special advantage that the bulk of the sludge is sensibly less than that obtained by lime.

The A B C process was made the subject of a special series of investigations by the Rivers Pollution Commissioners, with the following conclusions ;—

The process removes a large proportion of the suspended impurities from sewage, but rarely is this removal so complete as to render the effluent sewage admissible into running water.

The A B C process removes a very small proportion of the soluble polluting matters from sewage. After treatment by this process, the effluent sewage is very little better than that which is obtained by allowing raw sewage to settle in subsidence tanks.

The manure obtained by this process has a very low market value, and cannot repay the cost of manufacture.

The manipulations required for the extractions and drying of this manure are attended with a nauseous odour, especially in warm weather, and would occasion a serious nuisance if the works were situated in or near a town.

The name of the process has been taken from the initial letters of the three substances considered essential to the process, alum, blood, and clay, but other substances have been used, and the mixture of substances has suffered a great variety of changes. The following is stated in the final specification, as proportions which have answered well for ordinary sewage:—

Alum	600 parts.	Burnt clay	25 parts.
Blood	1 „	Common salt	10 „
Clay	1900 „	Animal charcoal	15 „
Magnesia	5 „	Vegetable charcoal	20 „
Manganate of potash ..	10 „	Magnesian limestone ..	2 „

The quantity required is stated to be about 4 lb. a 1000 gallons of sewage, equal to about 1$\frac{3}{4}$ tons a million gallons. In singular contrast to the above are the proportions most recently employed at Leeds:—

Alum, or sulphate of alumina ..	3 parts.	Clay	6 parts.
Charcoal of some kind	3 „	Lime	12 „

In this mixture the essential ingredients appear to be alum and lime, the latter being used in considerable excess, as appears from the composition of the dried sludge. As regards clay, it is a fact that sewage of some towns contains already too much of that substance; and what is added only increases the bulk and weight of the sludge, without offering any compensating advantage. One object of the addition of clay is to ensure rapid precipitation; but this appears to be equally well attained by the use of lime alone.

If a system of precipitation is adopted, the disposal of the sludge will be one of the most important elements in the calculation of cost. Probably it might be used to some extent for filling up waste and low-lying land; but, if not required for this purpose, it must be deposited in the same way as any other kind of soil.

Intermittent filtration as a means of purifying sewage has been carried out quite successfully by Bailey Denton at Merthyr-Tydvil; but the conditions are there so exceptional, that there are very few places where the process could be pursued with equally satisfactory results.

Many places are so situated that a water-carriage system for the removal of the excreta is almost an impossibility; and there are large towns where, even when a system of drainage has been carried out at enormous cost, the difficulties of dealing with the polluted waters at the outfall appear so insuperable, that a return to the pre-existing midden system, or to some form of interception, has become almost a matter of necessity.

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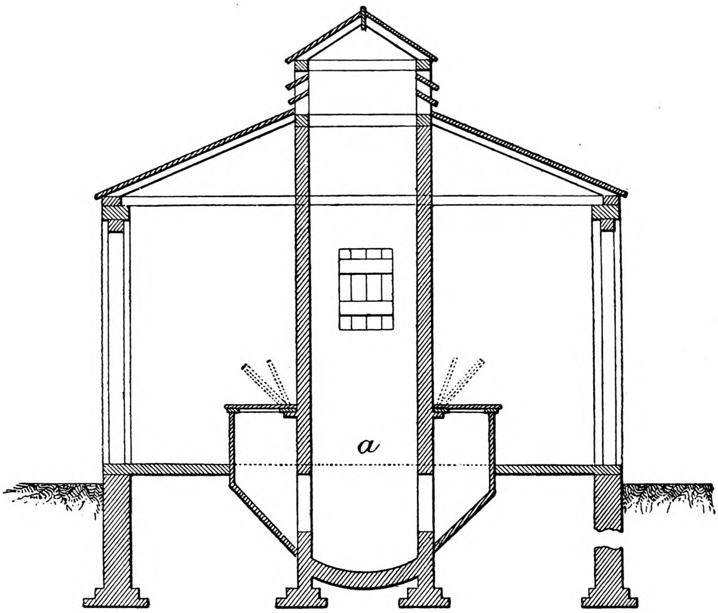

Even where a water-carriage system prevails, some plan of removing house refuse, ashes, and dust, some dry system of collection, must also be in force; while an interception system, however carefully it may be carried out, still leaves a vast quantity of slop water and surface drainage to be cleansed and defecated at the outfall.

No plan, however, will serve if there are leaky and pervious cesspools, an absence of proper urinals, ill-paved roads, and the filthy habits in the population generally, and difficulties may be reduced to a minimum by careful scavengering and strict supervision, both of which duties must be uncompromisingly and carefully performed in all towns and areas where cleanliness is sought after and enforced. The following account of the various forms of dry closets is from a paper by G. R. Redgrave in Trans. Inst. C.E., 1875–6.

The term interception implies the exclusion from the sewers or drains of all fæcal matters, and the possibility of interception involves the existence of a system of sewers, which may, however, have been laid down for the removal only of surface water and slops.

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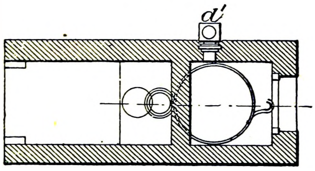

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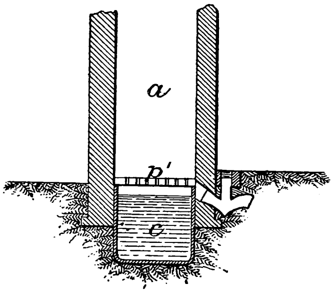

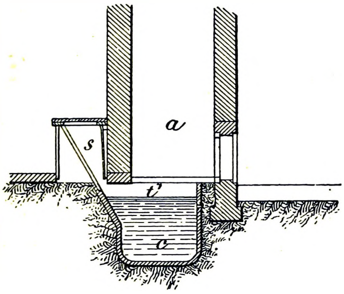

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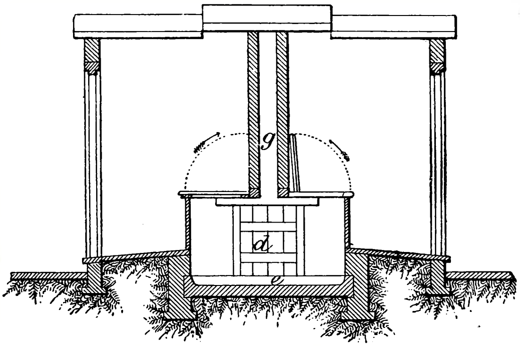

A midden or dry closet should under any circumstances be constructed of non-porous materials and furnished with a drain to carry off the excess of liquids, and it is an advantage if it has a simple arrangement for deodorizing the contents with ashes or some other available material which requires the form to be modified so that this may be accomplished readily.

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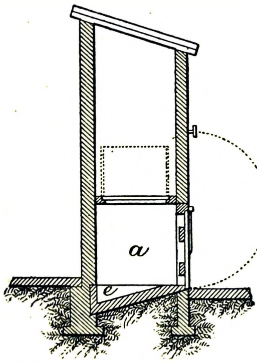

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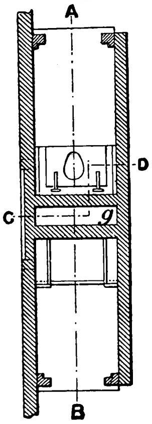

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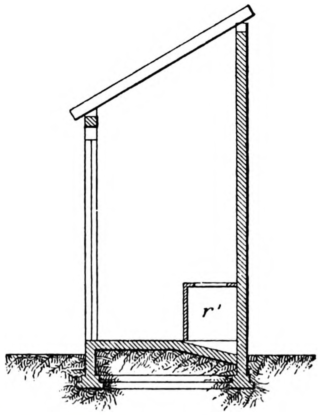
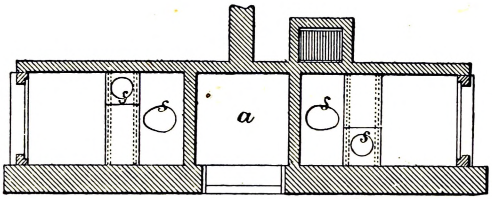
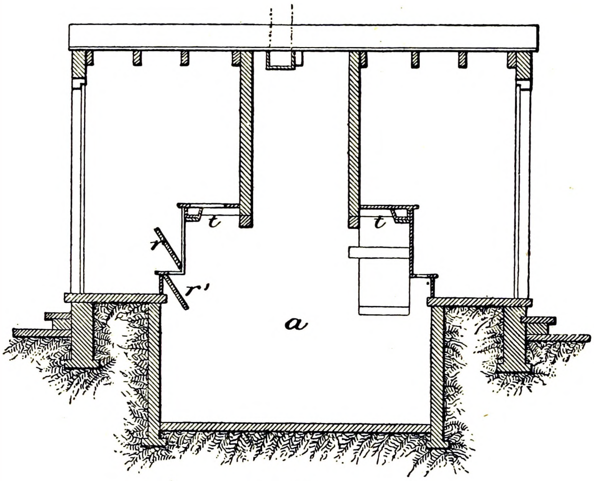


Figs. 2187, 2188 illustrate such an arrangement as used at Nottingham, and Fig. 2189 is a modification of this form employed at Stamford. In these examples the receptacle is concave, in order that the dejection may gravitate to the centre, and the brickwork is carefully cemented on the inside to render it impervious. There is also a special opening, through which ashes or earth may be thrown on to the contents, and a shaft is carried up for ventilation. The riser of the seat is of brickwork, or of 2-in. stone, the floors in both cases being also of non-porous material. Fig. 2189 is the better arrangement of the two, for here the seat is hinged so as to throw up and permit of the ashes being sprinkled on the freshly deposited contents, and as the pit is shallower, it necessitates more frequent cleansing. The midden, Figs. 2190 to 2192, is of glazed stone-ware, provided with an overflow pipe connected with the sewers, and is a good type, the cost being small, while the danger of leakage is avoided. *s* is the soil pan, *t* the trapped overflow, *c* the cesspool, *p* a perforated pitch-pine cover, and *a* a covered ash-pit, from which access can be had through an opening, as at the back on the level of the court. Where possible it is an advantage, when the size of the midden is reduced to a mere space underneath the seat, where this is formed of non-porous materials, or furnished with ready means for the removal of its contents, which must take place at the shortest possible intervals, of this class, those employed at Manchester and Hull, Figs. 2193 to 2196, and Figs. 2195, are good specimens. *a* is the ash-pit, *e* the bottom, *g* the air-shaft. Fig. 2193 has a glazed earthenware sloping bottom, with a door conveniently placed for emptying the contents, which operation takes place fortnightly. Fig. 2195 is similar in arrangement, but has a stone floor and no ventilating shaft and the pan being less capacious the midden has to be emptied weekly; the emptying takes place from the front in lieu of the sides, the riser of the seat being made movable for the purpose, which renders the plan somewhat defective. This latter arrangement, moreover, has less conveniences.

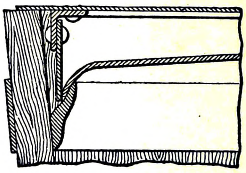
2197.



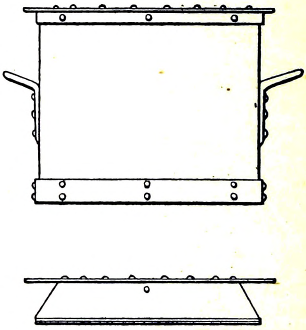


2198.

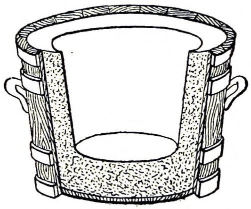
2201.



2202.



2199.



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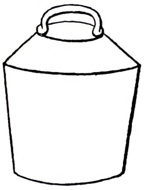
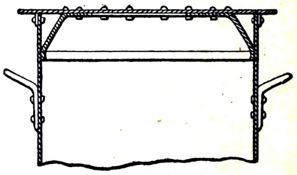


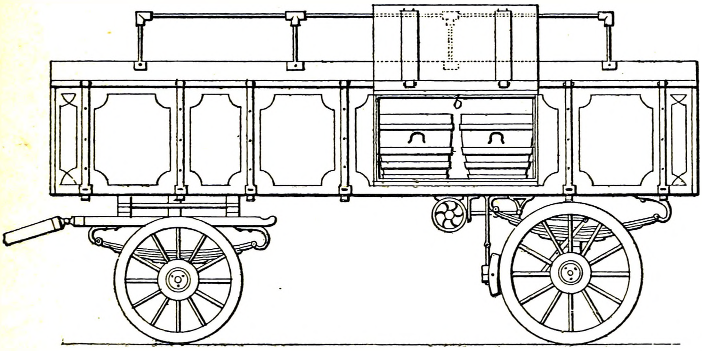


2203.

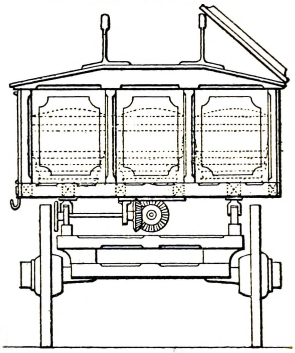
Figs. 2197, 2198, illustrate a midden that has been used at Stockport and Leeds. Here a trough *t*, placed under the front part ot the seat conveys away the urine to a separate receptacle, or direct to the drains. By this means, not only are the midden contents kept much dryer and an entire immunity is secured from splashing, but a smaller quantity of deodoriser can be employed for the solids, and there is little offensive smell. Fig. 2198 is a section of the centre line of Fig. 2198, *a* is a shaft, *r* are risers, which are made to open and serve as shoots, *v* the ventilating flue from the shaft, S is a step and child's seat, and *s* a seat for adults.

Many of the arrangements of these middens have been entirely altered by adopting movable receptacles, consisting of either tubs, pans, or pails; the simplest arrangement of this kind is merely a wooden box, placed under the seat so that when full it can be tipped into a scavenger's cart and replaced. The difficulty of cleaning out the angles of the box at first made use of, and its non-adaptation to closets of different shapes, led to the employment of oval or round tub-shaped receptacles; such are those in the Goux system used at Rochdale, Fig. 2199 being placed under the closet-seat. The Goux tubs are lined with some absorbent refuse material, rammed round a mould or core, Fig. 2200, which is allowed to remain in the pail until just as it is about to be placed under the seat, the core is then withdrawn and it is then ready for use.

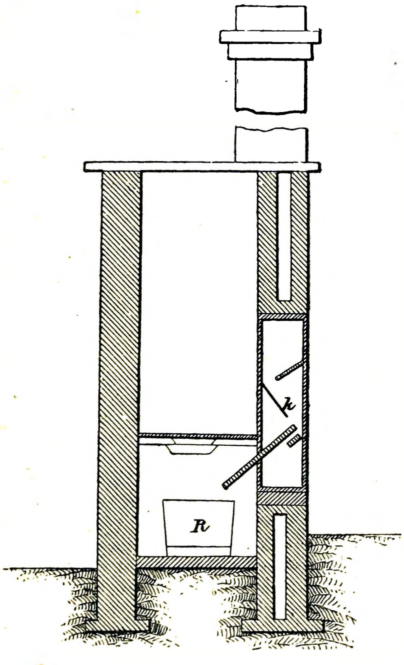
2204.



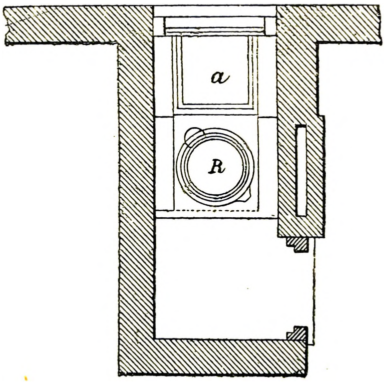
2205.



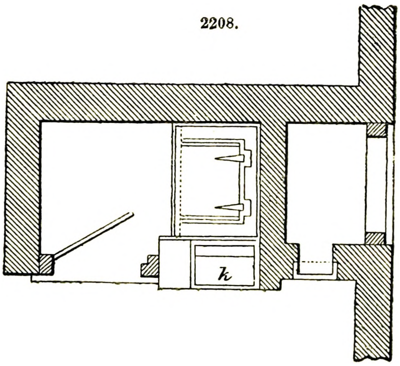
2206.



2207.



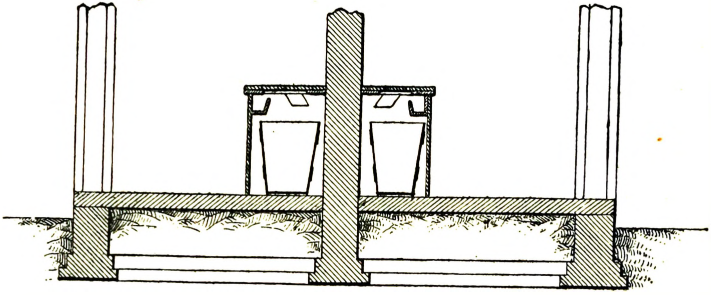
2208.



The proportion of absorbents in a lining is 3 in. thick to the central space in a tub, and, say 18 in. diameter would be about two to one, but unless the absorbents are dry, these proportions would be insufficient to produce a dry mass in the tubs when used for a week; and experience has shown that after being in use for several days, the absorbing power of the lining is already evaporated, and the contents become liquid. This system has been tried in several parts of England, but it would appear that although it removes the risk of splashing, and does away with much of the unsightliness of the contents, it is still a nuisance, and the absorbent, inasmuch as it adds weight to the pail, which has to be carried to and from the houses, is rather a disadvantage than otherwise, from a manurial point of view. After trial at Rochdale, this system has been modified by the employment of a pail, similar in every respect but omitting the absorbent lining. The tubs employed consist of a paraffin cask cut in half and furnished with handles. A strong cast-iron rib, Fig. 2201, is fixed in the inside of the tub, about three inches down, to form a stop for the lid. Galvanised iron tubs have been tried, but as their first cost is double that of the wooden ones, and as they only last about half the time, there does not appear to be much advantage from their use, although they are common in some places. At Birmingham, galvanized tubs, Figs. 2202, 2203, are in general use. The closets in Rochdale are all numbered consecutively, and a systematic collection from each of the six districts into which the town is divided, is carried out; by a well arranged mode of bookkeeping the collectors are checked in their work, and any omission at once ascertained, the work being done in the daytime, and every closet emptied weekly. The closets are provided with a door giving access to the space under the seat, and when the tub is removed it is at once covered with a lid and placed in a van, Figs. 2204, 2205, while a clean tub containing a small supply of disinfecting fluid is substituted for a full one taken away. Each van is arranged to hold 24 tubs, and makes 5 journeys a day. In 1874, 5 of such vans in full work collected weekly from 3354 closets in all parts of the town. The ashes and house refuse are deposited in a separate tub, but collected at the same time.

In many cases attempts have been made to deodorize the excreta by the application of absorbent materials, either alone or in association with the pail system. At Manchester a form of ash closet, Figs. 2206 to 2208, is extensively used. Fig. 2208 is a plan above the seat, Fig. 2206 a sectional elevation, and Fig. 2207 a plan of the floor. A cinder sifter K is here attached to the closet, and works in combination with a pail receptacle R. This sifter is so arranged that the ash is directed by a shoot on to the contents of the pail, and the cinders fall into a bucket, whence they may be taken for reburning; it would appear, however, that there is little to be gained in the method of deodorization by the use of ashes. The arrangement for the pail system with separate urine collection is illustrated by Fig. 2209.

2209.



Probably the best-known contrivance for deodorizing and disinfecting the deposit in dry closets, are those in which advantage is taken of the deodorizing qualities of dry earth, which were brought into permanent notice by H. Moule. In these closets a supply of earth contained in a hopper behind the seat is thrown on to the contents deposited, by the action of an ordinary pull-up handle similar to the pull of the water-closets, or by the weight of the user acting on a balance seat or foot-board, or by both combined.

Bond's earth closet is arranged so that the vessel fixed beneath to contain the dejections, receives the liquids and solids into separate compartments. A box for the supply of the deodorizing material, consisting of sifted ashes, is attached to the lid, and the person on entering the closet raises the lid, and by so doing measures out a charge of the deodorizer; on leaving the seat he closes the lid, and by this means he discharges the ashes over the solid contents. In Moser's universal closet, the deodorant stored in a chamber at the back of the seat is spread in measured quantities by a pair of bellows actuated by a lever handle. Gibson's dry closet has a movable shoot attached to a hopper. This receives a small quantity of the deodorizer, and distributes it by an action similar to that of a shovel. There is also an arrangement for receiving the liquid and conveying it direct to the drain. All such contrivances as these aim at economizing the quantity of the dry deodorizer, and it is argued that if the user of the closet can be prevailed upon to avail himself of mechanical means for deodorization he is as likely to avail himself of dry material stored conveniently for the purpose, so that it may be thrown over the deposit with a hand scoop. All mechanical devices are more or less liable to get out of order, and are therefore ill adapted to rough populations; the supply of earth, too, amounting to 4½ lb. a head, renders the cartage to and from the depots exceedingly great when used for a large population, and the urine has still to be dealt with unless it is run direct into the sewers. Animal charcoal is such an excellent deodorizer that when the liquid is kept apart from the solids, from ½ oz. to ¾ oz. will suffice, if carefully distributed after each use of the closet, to remove all disagreeable smell from the solids. The Carbon Fertilizer Company utilize this method, and also employ a good separator pail for keeping the liquids apart from the solids. This is effected by a horizontal perforated diaphragm. This plan of separation is the only one that answers where slops are also thrown into the pail.

List of Books on Sanitary Engineering.—'The Sanitary Drainage of Houses,' by G. E. Waring, jun., crown 8vo., Boston, U.S., 1879. 'Bye-Laws and Regulations for House Drainage,' by Rogers Field, 8vo., 1878. 'Sanitary Works Abroad,' by R. Manning, 8vo., 1876. 'Sewers and Drains for Populous Districts,' by Julius H. Adams, 8vo., New York, 1880. 'Sanitary Engineering: a Guide to the Construction of Works of Sewerage,' by Baldwin Latham, 8vo., 1878. 'The Purification of Water-carried Sewage,' by H. Robinson and J. C. Mellis, 8vo., 1877. 'Sanitary Engineering: a Course of Lectures at Chatham,' by J. Bailey Denton, royal 8vo., 1877. 'House Drainage and Water Service,' by J. C. Bayles, 8vo., New York, 1879. 'American Sanitary Engineering,' by E. T. Philbrick, 8vo, New York, 1880. 'A Hand-Book of Formulæ, Tables, and Memoranda for Architectural Surveyors,' by J. T. Hurst, royal 32mo., 1879. 'Proceedings of the Association of Municipal and Sanitary Engineers,' 6 vols. 8vo., 1874–80. 'Sanitary Work in the Smaller Towns and in Villages,' by C. Slagg, crown 8vo., 1876. 'Sewage Disposal,' by H. Robinson, crown 8vo., 1880. 'Ten Years' Experience in Works of Intermittent Downward Filtration,' by J. Bailey Denton, royal 8vo., 1881. 'The Pneumatic Sewerage System,' by Isaac Shone, 8vo., 1880. 'Sewer Gases, their Nature and Origin,' by A. D. Varona, 18mo., New York, 1879. 'Dirty Dustbins and Sloppy Streets: a Practical Treatise on the Scavengering and Cleansing of Cities and Towns,' by H. P. Boulnois, crown 8vo., 1881. 'The Plumber and Sanitary Houses,' by S. S. Hellyer, 8vo. 'Suggestions as to the Preparation of District Maps and of Plans for Main Sewerage and Water Supply,' by R. Rawlinson, fcap. folio, 1878.

SHAFTS AND SHAFT FITTINGS.

Shafts for transmitting power and motion are the most generally employed, and also the oldest mechanical contrivances, and for that reason we should expect to find them among the most perfect in their arrangement and construction, but this is far from being the case; for if we examine the great variety of couplings, bearings, and hangers, which are adopted by different makers of shafting, and the diversity of opinion which exists as to the relative merits of each system, we shall see at once that the manufacture and erection of shafting is far from being a perfect art either in practice or in theory.

In arranging the shafting for a mill, factory, or machine shop, two systems are open to us for adoption, the one system being known as the overhead, the other as under-floor shafts; but except in cases where it may be necessary to employ very heavy shafting, or under very special circumstances, the system of under-floor shafts is one that should not be adopted, for they increase the danger of fire, and occupy much valuable floor space. In regard to the first, especially in factories where fibrous material or wooden wares are manufactured, a concealed pit shaft causes more anxiety, and calls for more circumspection, than a whole factory besides. Belts passing down through a floor carry with them, by the air currents induced, much of the light dust arising from machines, and generally, we may say unavoidably, shavings or other débris, so that shaft pits become in effect tinder-boxes. A piece of iron, a stone, sometimes even a nail, coming in contact with an iron pulley running at a great speed, will cause a shower of sparks to be discharged, and in an instant all is in flames. The air currents caused by the motion of pulleys and belts in a confined room carry the flames into all parts of the pit in a moment, and the result is often the destruction of a factory. In respect to floor space, it is seen at once that belts coming down from overhead shafts to machines consume the least possible amount of useful room, while holes cut through floors to accommodate belts, with the safety cases which must surround them, consume much valuable space; besides which the arrangement of most factory machines, especially machine tools for iron, renders overhead countershafts indispensable. Another matter worthy of consideration in connection with these two systems is, that the cost of warming a factory in winter will often be doubled by reason of a large number of belts passing through the floors; in such cases, the shaft pit or a lower story has to be warmed as well as the machine floor, and air currents sweep around operators who attend machines in such a way as to render it impossible to keep warm; on the contrary, belts carried down from overhead shafts tend to circulate the warmer air collected at the ceiling. A line shaft adapted for earth supports and mounted on masonry, is generally made from one-third heavier to twice as heavy as a shaft for the same duty would be if suspended from the ceiling. The fittings may be of the cheapest construction, the bearings rigid and massive, pulleys heavy and unbalanced, and the couplings such as to withstand torsional strain only. The cost of erecting on earth foundations is also much less, and the shafts being in most cases hid from view, may run out of truth without much interfering with their functions. On the contrary, line shafts adapted for suspension to ceilings, and over the machinery they are to drive, require to be of a minimum weight, and must be more carefully fitted; the bearings should be pivoted, and so arranged that the shaft may be readily adjusted up or down to suit the settling of floors, or of pillars on which floors are supported. Couplings on suspended shafts have not only to transmit the torsional strain of the work performed, but must be secure enough to withstand the bending strains from a shaft being more or less out of line; and as the shafts are one of the first objects seen in entering a factory, it is necessary that they run true and without noise, the pulleys being turned true and balanced.

A line shaft, as a machine for transmitting motion, is made up of many parts, possessing varied functions; the independent bars of which it is formed must each be made truly cylindrical, and they must then be securely united one to the other, by some coupling, of which many kinds exist, and will be described later. This line of shafting must then be supported at regular intervals in suitable bearings, which must be so arranged as to allow the shaft to rotate freely about its longitudinal axis, while at the same time they support and maintain that axis in a right line. The number and position of these bearings will be regulated by the position of the wheels and pulleys on the shaft; but in all cases the bearings should be as near as possible to the couplings, pulleys, etc. It sometimes, however, happens that in a long shaft there may be no pulleys or gearing upon it for several feet, and the distance between the bearings must then be arranged proportionate to the stiffness of the shaft itself. Assuming 10 ft. as a safe distance for the bearings of an unloaded shaft 2 in. in diameter, and that the deflection may in all cases be proportional to the distance between the bearings, we have the following rules:—

$$L = \sqrt[3]{(d \times 16)^2} \text{ or } d = \sqrt{L^3} \div 16.$$

In which d = diameter of the shaft in inches, and L the length between the bearings in feet. The following Table has been calculated by this rule, but it must be understood that the distances given apply only to shafts having simply their own weight to carry:—

Diameter of the shaft in inches	1	1½	2	2½	3	4	5	6	7	8
Distance between the bearings in feet	6·3	8·3	10·1	11·7	13·2	16·0	18·6	21·0	23·2	25·4

Another rule gives the distance between bearings, for shafts loaded in the centre, with pulleys not more than five paces in diameter, as

$$L = d25,$$

in which d = the diameter of the shaft in inches, and L the distance between the bearings in feet, as before.

The strains to which shafts are subjected in transmitting power are the torsional strains of transmission, transverse strains from belts and gearing, and accidental strains, arising from winding belts or other cause; and of these three the last is always the greatest, so that if we make the shafting sufficiently strong to resist these accidental strains, the other two may be safely disregarded. The torsional strength of a shaft varies inversely as its diameter, while its torsional deflection increases with the length. For these reasons the system has often been adopted, when erecting a long line of shafting, which has to give off power at various portions of its length, of giving to it what may be termed a tapering form; that is, the first section would be of sufficiently large diameter to transmit the maximum power required, say 3 in., the second 2¾ or 2½ in., the third 2½ or 2 in., and so on to the end; but this system, except in altogether exceptional cases, is to be avoided, as it at once reduces the shaft to the nature of a special machine. Any little saving in first cost which may be effected by employing these reduced diameters, will be quite swallowed up by the increased cost and trouble of fitting and fixing; while at the same time it does away with all symmetry of appearance in the shaft and its fittings, and prevents all interchange or shifting of pulleys, couplings, or supports, from one section of the shaft to another, which in the case of a rearrangement of the machines in a shop, or the introduction of new machines, is often a matter of great convenience and economy. Again, if the diameter of a shaft were calculated and fixed with reference only to the exact amount of power to be transmitted, or if its diameter at various parts were based upon the torsional strain that would be sustained at these points, such a shaft would not only fail to meet the conditions of practical use, but would cost more by such an adaptation.

In proportioning shafts for belting much must be left to judgment, and be dictated by that peculiar sense of realising what is wanted from previous experience. There are in fact so many obscure conditions which have to do with the matter, that any rule must be an arbitrary one, if given for general application. The shafts with their supports should, however, always possess sufficient strength to tear the belting asunder without damage to the machiner, for it is impossible always to prevent the accidental winding of a belt, and when such an accident does happen it is always much easier to replace or splice the belt, than it would be to repair the shafting or machinery. Experience has shown that for ordinary cases, where the power transmitted is applied with tolerable regularity, a shaft 3 in. in diameter, with its bearings four diameters in length and placed 10 ft. apart, and running at a speed of 150 revolutions a minute, is a proper size to transmit 50 horse-power. A generally safe rule as regards strength is to make

$$d = \sqrt{w};$$

where w equals the width of the belt, and d the diameter of the shaft, both in inches. For gearing shafts require to be stronger than for belts; the motion being positive and lacking in that elasticity which exists in belt connections. In the article on "Belts and Belting," at page 112, will be found a table giving the horse-power transmitted by shafts of various diameters at a speed of 100 revolutions a minute; and in Table I., which is taken from Box's 'Treatise on Mill Gearing,' are given the weights of round and square wrought and cast iron shafts, from ⅛th of an inch to 14 inches in diameter.

TABLE I.—WEIGHT OF SHAFTS 1 FOOT IN LENGTH.

Size in Inches.	Weight in lb.				Size in Inches.	Weight in lb.				Size in Inches.	Weight in lb.			
	Wrought Iron.		Cast Iron.			Wrought Iron.		Cast Iron.			Wrought Iron.		Cast Iron.	
	Round.	Square.	Round.	Square.		Round.	Square.	Round.	Square		Round.	Square.	Round.	Square.
⅛	·042	·053	·038	·048	2⅝	18·2	23·2	16·6	21·1	7¼	139	177	126·5	161·1
¼	·166	·211	·151	·192	2¾	20·0	25·5	18·2	23·2	7½	149	190	135·6	172·9
⅜	·372	·474	·338	·431	2⅞	21·9	27·9	19·9	25·4	7¾	159	203	144·7	184·7
½	·662	·843	·602	·767	3	23·8	30·3	21·7	27·6	8	169	216	153·8	196·6
⅝	1·03	1·32	·937	1·20	3¼	28·0	35·6	25·5	32·4	8¼	180	229	163·8	208·4
¾	1·49	1·90	1·36	1·73	3½	32·4	41·3	29·5	37·6	8½	191	244	173·8	222·0
⅞	2·03	2·58	1·85	2·35	3¾	37·2	47·4	33·8	43·1	8¾	203	258	184·7	234·8
1	2·65	3·37	2·41	3·07	4	42·4	54·0	38·6	49·1	9	214	273	194·7	248·4
1⅛	3·35	4·27	3·05	3·89	4¼	47·8	60·9	43·5	55·4	9¼	227	288	206·6	262·0
1¼	4·14	5·27	3·77	4·80	4½	53·6	68·2	48·8	62·1	9½	239	304	217·5	276·6
1⅜	5·00	6·37	4·55	5·80	4¾	59·7	76·0	54·3	69·2	9¾	252	320	229·3	291·2
1½	5·97	7·58	5·43	6·90	5	66·2	84·3	60·2	76·7	10	265	337	241·2	306·7
1⅝	7·00	8·90	6·37	8·10	5¼	72·9	92·9	66·3	84·5	10½	292	372	215·7	348·5
1¾	8·11	10·3	7·38	9·37	5½	80·1	102·	72·9	92·8	11	320	408	219·2	371·3
1⅞	9·31	11·8	8·47	10·74	5¾	87·5	111·	79·6	101·0	11½	350	448	318·5	407·7
2	10·6	13·5	9·65	12·29	6	95·3	121·	86·7	110·1	12	381	486	346·7	442·3
2⅛	11·9	15·2	10·83	13·83	6¼	103·	132·	93·7	120·1	12½	414	527	376·7	479·6
2¼	13·4	17·1	12·2	15·6	6½	112·	142·	101·9	129·2	13	447	570	406·8	518·7
2⅜	14·9	19·0	13·6	17·3	6¾	121·	154·	110·1	143·1	13½	483	614	439·5	558·7
2½	16·5	21·1	15·0	19·2	7	130·	165·	118·3	150·2	14	519	661	472·3	601·5

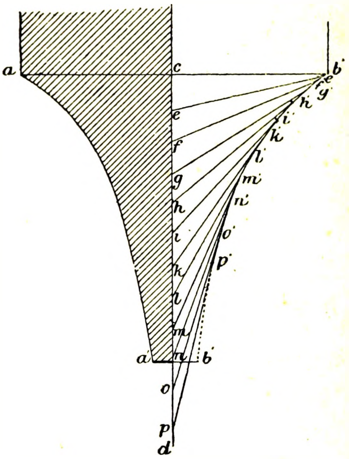
In the United States shafting of cold rolled iron is very extensively employed in preference to turned shafting, over which it possesses the advantages of increased strength, hardness, and elasticity in a very marked degree. The making this cold rolled iron is a very simple process, as carried on by Laughlins, of Pittsburgh, Pennsylvania, who have made a speciality of this manufacture, and by whom it is produced in large quantities, not only for shafting, but also for piston-rods, and for the finger-bars, knife-backs, and guard-bars for reaping and mowing machines. The bars are first rolled hot, to within about one-eighth of an inch of their ultimate size; they are then placed in acid, in order to remove the surface impurities; and are finally reduced to the required dimension by the special process of cold rolling. The bars thus made have a highly polished and perfectly smooth surface, and are as true as if turned in a lathe. The following table gives the results of a series of experiments, comprising about sixty tests, which were made by W. Wade, of the United States Ordnance Department, for the purpose of testing the relative merits of hot and cold rolled iron; and from them it will be seen that the results are greatly in favour of the cold rolled:—

TABLE II.—COMPARISON OF HOT AND COLD ROLLED IRON FOR SHAFTING.

	Iron rolled while		Ratio of Increase due to cold Rolling.	Average Rate of Increase per cent.
	Hot.	Cold.		
	lb.	lb.		
I.—TRANSVERSE STRAIN:—				
Bars supported at both ends, distance between bearings 30 in.; load applied at centre.				
Weight which gave a permanent set of $\frac{1}{10}$ in. to				
Bars, 1½ in. square	3100	10700	3·451	162·5
Round bars, 2 in. diameter	5200	11100	2·134	
,, ,, 2½ in. ,, ...	6800	15600	2·294	
II.—TORSION:—				
Weight giving a permanent set of one degree, when applied at a distance of 25 in. from the centre of the bar:				
Round bars, 1¾ in. in diameter, and 9 in. between the points of attachment	750	1725	2·300	130
III.—COMPRESSION:—				
Weight giving a permanent set of $\frac{1}{100}$ in. to columns 1½ in. long and ⅝ in. diameter	13000	34000	2·615	161·5
Weight giving a permanent set to columns 8 in. long and ¾ in. diameter:				
Puddled iron	21000	31000	1·476	64
Charcoal bloom iron	20500	37000	1·804	
IV.—TENSION:—				
Weight a square inch, giving a permanent set to rods ¾ in. diameter:				
Puddled iron	37250	68427	1·837	95
Charcoal bloom iron	42439	87396	2·059	
Breaking weight a square inch for the same rods:				
Puddled iron	55760	83156	1·491	72
Charcoal bloom iron	50927	99203	1·950	
V.—HARDNESS:—				
Weight required to produce equal indentation	5000	7500	1·500	50

The regular working strain to which a shaft is subjected varies inversely with the speed at which it is driven; and this, on account of its influence as regards economy in the first cost of a line shaft, would be a sufficient reason for arranging the same to run at a high speed; but there are other and weightier conditions which all tend to favour the same arrangement. And first among these is the saving of cost in countershafts; for it is obvious that if the speed of the line shaft varies so considerably from that required in the first movers of the machines as to necessitate the employment of one or more countershafts between the main line and the machine, not only will the first cost of shafts, fittings, and belts be greatly increased, but also the cost of maintenance; while the obstruction arising from belts and pulleys will also be increased. The practical limit of speed in a shaft is, however, greatly dependent upon the nature of the bearings; these should be pivoted to allow of the self-adjustment of the shaft, and should be four diameters in length. For the bearings of line shafts cast iron is undoubtedly, for many reasons, the best substance to employ; it is the cheapest and most easily worked into shape, while if kept properly oiled it is the most durable of metals, although the poorest if allowed to run dry; with a pressure not exceeding 50 lb. a square inch, and oil well distributed over the surface of the box, the shaft will run on the oil used for lubricating without touching the surface of the box, the oil under this pressure is not squeezed out but will maintain its lubricating properties for a long time. The use of Babbitt's metal, or other soft metal, is often advocated for bearings, and though there are many cases in which it may be advantageously employed, its use for the bearings of line shafts is to be altogether discouraged. All soft metals, while they do not cut when permitted to run dry, as cast iron is sure to do, yet serve to catch the grit and dirt in the atmosphere which finds its way in with the oil; the soft metal holds these little sharp particles, and thus gradually grinds down the shaft running in it. As an example of this abrasive power of soft metals, we may instance the means adopted when it is desired to grind down a cylinder of hard metal; lead clamps, very similar to journal boxes, are applied to the cylinder, and into these clamps oil and emery are fed, the lead holds the emery, and by the continued revolution of these clamps around the cylinder, the size of the hard metal is reduced without any serious wear on the part of the lead. These soft metal bearings are generally advocated on the score of economy, the following reasons being advanced in their favour. The boxes for these bearings are cast with a recess to hold the soft metal, and can be used just as they come from the foundry, thus dispensing with all labour and cost of boring and fitting; the shaft is laid in its place on the cast-iron shell, and the soft metal, previously melted in a ladle, is poured in, thus filling the recess and ensuring a fit. Against this, however, we have the following facts. The box cast with a recess, in order to be of equal strength to one cast solid, must be made rather larger, and this increase of size, as it increases the weight of metal in the box, will also add to its cost. Again, Babbitt's metal costs much more than cast iron, generally ten times as much; while the melting, pouring, and fussing over the job all take time, which means money. It may be safely said that a pair of cast-iron boxes can be planed on their faces, then bored to fit the shaft, and grooved for oil passages, for less than one-half the cost of the least quantity of soft metal which could be used in such a box. For vertical shafts the Schiele curve is undoubtedly the true form of bearing to resist end-thrust with high speed. The great fault with all bearings, when the plane of the surfaces is transverse to the surfaces in motion, is that they move on each other at different degrees of velocity; varying from the centre to the periphery, directly as the diameter. The Schiele curve of equal tangents is a theoretical, and for that matter practical attempt, to obviate this infraction of mechanical principles, by taking up end-thrust on surfaces having a uniform connection for resisting wear. The method of constructing this curve is shown in Fig. 2210. Let $a\,b$ be the diameter of the shaft; bisect the line $a\,b$ at c, and from c erect the line $c\,d$ perpendicular to $a\,b$. From c lay off any number of equal parts, as e, f, g, h, &c.; join $e\,b$, and in the line $e\,b$ lay off the distance $e\,e'$, equal to $a\,b$; join $f\,e'$, and lay off the distance $f\,f'$, also equal to $a\,b$; and so proceed, joining the point last found, as f', to the next division in the line $c\,d$, as g, and making each of the distances $e\,e'$, $f\,f'$, $g\,g'$, $h\,h'$, &c., equal to $a\,b$; then c', f', g', h', &c., will be the points through which to draw the curve as shown in the figure. W. Sellers and Co., of Philadelphia, have adopted a plan for stepping vertical shafts, which is almost the very opposite of the old point theory, that of wide, flat surfaces. A disc, or collar, is formed on the end of the shaft, resting on a corresponding plane, in the face of which there are radial curved oil grooves, the action of which corresponds to the furrows in the faces of mill-stones; the oil is fed to these surfaces through a central opening, and discharged upon the periphery, returning through proper channels to the reservoir, to be again taken up. This, for heavy thrust and motion that is comparatively slow, is no doubt as good a plan as can be adopted for the end of shafts. (See p. 1586 of this Dictionary.)

2210.



J. Richards, in his 'Woodworking Machinery' and in his 'Operator's Handbook,' gives the following particulars concerning shafting;—

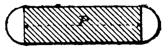
"Shafting for operating wood machines, like nearly everything else pertaining to them, require to be special in many regards. The speed of the main lines should, for the most economic and simple arrangement, never be less than three hundred revolutions a minute, which is alone a sufficient distinction from ordinary cases to warrant the statement of its being special. An average speed for countershafts, or first movers in wood machines, is about three times as much, which gives as a rule a proportion of three to one between the pulleys of the line and the counter shafting. Shafting of from $2\frac{1}{2}$ to $3\frac{1}{2}$ in. diameter running at this speed must be true as to turning and straightness; the pulleys must be carefully balanced, and the bearings long and pivoted, with careful provision for lubrication. There is as a rule more belting to be carried on the shafting of wood-working manufactories than in those of other kinds. This is directly as the amount of power employed, with enough added to make up for the dry state in which the belting has to operate. The usual large amount of belting makes a great strain upon the bearings, especially as it must be tightly stretched to obtain traction. Taken upon the whole, a factory of this kind requires the best of shafting, and the greatest care in its operation, or else the delays from the derangement will be frequent and long.

"The sudden starting of heavy machines by means of shifting belts, or more especially by means of slack belts with tightening pulleys, subjects the shafting and its connections to severe torsional strain, and is very apt to loosen the couplings unless well fitted or of the compression kind, which is in fact the only kind adapted to wood-working factories, and, for that matter, anywhere else. A coupling that is driven on and wedged, we will not term it keyed, when once removed and then replaced never runs in perfect truth; besides, at a second or third removal the fit is destroyed, unless a tapered one. For wood-working factories good compression couplings should be used, such as will ensure the continued strength of the shaft through the connection, and grip it so that no movement can take place by torsional strain. The keys should be deep; that is, wide on their bearing surfaces, and never bear on their back; a rule that applies however in all cases, for nothing but the most clumsy and unmechanical fitting ever confounds a key with a wedge.

"Pulleys for line shafting running at high speed should be light and true; weight is to be avoided on account of torsional strain from momentum, and perfect truth is needed to prevent a kind of oscillation, or vibration that takes place when the strain of belts is not uniform; in short, the shafting about a wood-working establishment should be first class in all respects; whatever contributes to its good performance at slow speeds becomes doubly important at high ones. Pulleys for wood-cutting machines should be strong, and safe from the danger of centrifugal strain due to high speed. Cast-iron pulleys with proper proportions, and made of close strong metal, are comparatively safe with their rims moving 5000 ft. a minute, a limit, however, which should not be exceeded. Such pulleys are as a rule turned both on the outside and inside of the rim, which should be rather heavier than usual. We give a formula from the Industrial Works, W. B. Bement and Son, of Philadelphia, which furnishes proportions that are well adapted for high speed pulleys:—

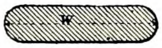
Diameter of pulley $= D$.
Face of pulley $= F$.
Diameter of pulley pattern $= D + \left(\frac{1{\cdot}25\,D + 10}{100}\right)$.
Face of pulley pattern $= F + \left(\frac{D + F}{100}\right)$.
Edge thickness of rim, $E = \left(\frac{\frac{1}{2}D + 8}{100}\right)$ an increasing progression, $A = 8\frac{1}{2}$, $R = \frac{1}{2}$, $N = D$.
Centre thickness of rim, $C = {\cdot}03\,F + E$.
Number of arms N; when $D > 12$, $N = 5$; $D > 30$, $N = 6$.
Breadth of arm at rim, $B = \frac{\sqrt{D \times {\cdot}6\,F + 10}}{N}$, increasing 1 in 16.
Thickness of arm, $T = \frac{1}{2} B$, parallel from rim to hub.

2211.



Hubs.

2212.



Parallelogram of web, $P = \sqrt{D + F}$, shown in Fig. 2211.
Web of hub, $W = P + T$, as shown in Fig. 2212.
Diameter of shaft to be used $= S$.
End diameter of hub, $H = \frac{\sqrt[3]{D + F}}{4{\cdot}5} + S$, or $\frac{P}{4{\cdot}5} + S$, increasing 1 in 16 to web.
Metal thickness of hub, $M = \frac{P}{9}$ when set-screw bosses are used, for *s p* line add $\frac{1}{2}$ to M.
Versed sine of facial curvature $= \frac{F}{64}$ for high faces.

"Hangers, or supports for overhead shafting, have undergone more modification, and are produced in a greater variety of forms and plans of adjustment than almost any other detail in machinery. That taste as to design has been the main reason of this is evident in the fact that a number of engineers would, with the same premises, generate about the same thing. A greater uniformity of strength, if not of design, would certainly exist if it were not for the contingency of winding belts, with other accidents, that can be set down under the general head of accidental strain. In wood-working mills and factories there is less danger from winding belts because of their being dry, but when such accidents do occur they are more serious because of the greater width and strength of the belts. Hence all hangers for wood-cutting machinery should have extra strength, especially for overhead shafts, and be, with their supports and bolts, strong enough to part or tear the belting without other danger. To determine the cross-section of a pendant support that will do this is not an easy matter, but experience and judgment will generally suggest proportions that are strong enough. A cored section is, without doubt, the strongest one for hangers, which form no exception to the rule for columns or beams, of disposing the material as far as possible away from the neutral axis and on the periphery.

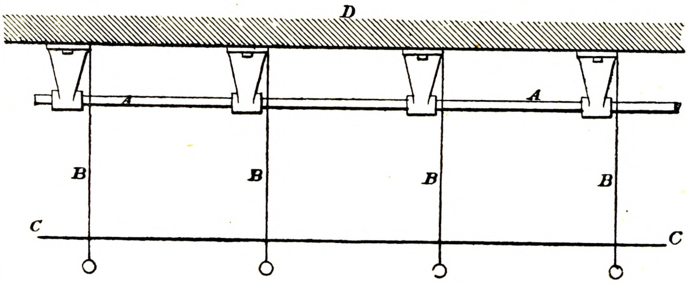
"In preparing plans for a wood-working mill, the shafting should, whenever practicable, go across the building. By belting from one line to another at one side of the room the whole power is not transmitted through the couplings, as in the case of one continuous shaft to drive all the machinery. The work is also divided more evenly throughout the several lines, and this does away with the supposed necessity of having the line shafting in sections of various diameters, which prevents the interchange of pulleys from one shaft to another, and often leads to expense and trouble. The first section of shafting, carrying the main driving pulley, should have a diameter equal to one-fifth the width of the main driving belt, and should be supported at each side of the main pulley; and this section should not be more than twenty diameters long between the bearings.

"For wood shops, $2\frac{1}{2}$ in. and 3 in. shafting are the best sizes; $2\frac{1}{2}$ in. shafts are as small as any should be, and they should not, without some important reason, exceed 3 in. in diameter. A line of $2\frac{1}{2}$ in. shafting will run safely and well at 250 revolutions a minute, or a 3 in. line will run 200 revolutions a minute, if the bearings are properly made, and it is kept in line.

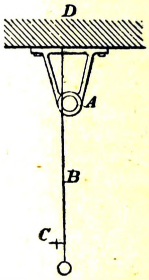
"Pulleys should be as light as possible, both as a matter of economy and convenience, and they should be turned true and balanced, balanced perfectly, no matter what their speed. The effect of an unbalanced pulley is as its speed, but it is never known where pulleys may have to be used in changing, and the only safe rule is to have every pulley carefully balanced, no matter what the speed may be at which they run.

"Couplings should be adjustable or compressive, not keyed on, or wedged on, for only such a key should be used as will not keep a solid coupling on. Hangers to support line shafting should always have their bearings pivoted, and adjustable vertically; for if the bearings have a vertical adjustment in the hanger frames, and are moved by screws, as they should be, it is a small matter to take a ladder, a level, and a wrench, and go along the line to level it; 100 ft. of shafting may be adjusted in this manner in an hour, if the larger belts are thrown off to relieve it from strain, and the shafting is straight and true. Shafting is not liable to get out of line horizontally, unless from the strain of belts; it is, however, well to line up as often as twice a year to be sure that all is right. A shaft may be levelled by almost anyone when the hangers are properly made, and can be done at noon, or after stopping in the evening, without interfering with the business at all. To line a shaft horizontally is but little more trouble if the bearings or hangers can be moved in that direction. Suspended hangers should have the bolt holes slotted for an inch or more of movement, and post hangers should have movable bearings that permit side adjustment. Assuming that there is some means of moving the shaft horizontally, a good plan of adjusting is by suspending a number of plumb-lines that will bear against one side of the shaft, and reach down low enough to be sighted from the floor, or for greater accuracy a strong line may be stretched about 5 ft. from the floor to gauge the plumb-lines from, as shown in Figs. 2213 and 2214. D is the ceiling to which hangers are bolted; A the line shaft; B the plumb-lines resting against the shaft, near to the bearings; and C a horizontal line stretched below the shaft. The lower line, C, can at the beginning be set within about $\frac{1}{8}$ in. of the two plumb-lines at the ends, and the rest can then be adjusted to the same position by moving the bearings, or the end bearings can be also adjusted, as the case may require. A ball of strong packing thread, and half-a-dozen or more old screw-nuts for the plumb-lines, make the outfit, and the job can be well executed at but little expense and time, if the hangers are properly made, and erected so as to be adjusted without trouble.

2213.

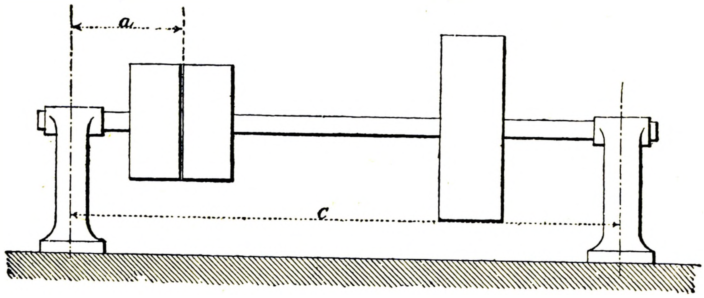


2214.

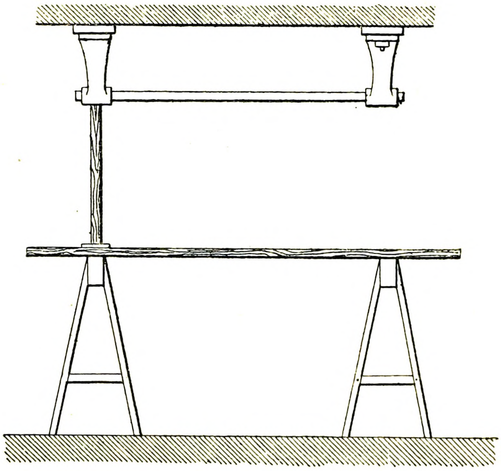


"In erecting a countershaft, the first things to be determined are the position of the machine it is to drive, and whether the belting is clear. When a line shaft is crowded with pulleys it often requires great care to place the countershaft so that belts will not interfere with each other; it is no uncommon thing for a shaft to be put up, and then the discovery made that belts interfere with others on the opposite side of the line shaft. Be careful in starting, that is the great point, not only in putting up shafts, but in all other mechanical operations that involve calculations and accurate measurements. As an example, let us suppose that a countershaft is to be erected, and go through the various operations, one at a time. Beginning with the hanger plates, these should be of hard wood, long enough to reach from two to four joists, as the weight of the shaft and belting may require; their width should be from one and a half to twice the width of the hanger base, and their thickness, as an approximate rule, one-fifth the drop of the hanger. When the joists are of hemlock, or harder wood, and 3 in. or more thick, almost any kind of shafting can be hung with safety on wood screws, or lag screws as they are sometimes called, passing through the hanger plate, and screwed directly into the joists. These screws should be of good size, not less than $\frac{5}{8}$ in. in diameter in any case, and long enough to pass into the joist a distance at least equal to the thickness of the hanger plate. A plate 3 in. thick requires, with cast-iron washers, screws that are 7 in. long; if one in each joist $\frac{7}{8}$ in. diameter; if two in each joist $\frac{3}{4}$ in., or $\frac{5}{8}$ in. will do for ordinary countershafts. Having the hanger plates ready, next mount the shaft in the hangers and invert them to stand on a level floor, Fig. 2215, and after settling the shaft to see that the bearings are not cramped, and that the hangers stand fair on their base, measure between the bolt holes accurately, or what is better, cut a short strip of wood to the length between the centres, marked *c* in the figure. If the shaft is to be placed to suit some pulley on the line shaft, measure from the centre of the hanger next the loose pulley the distance to the centre between the tight and loose pulleys, as at *a*; this should also be marked on the stick as the base for the position of the shaft: we will term it the driving belt line. This belt line must then be determined and scribed on the joist; it is easily found from a pulley, or by measuring from a wall or girder that crosses the line shaft at right angles. Placing the measuring stick with this base mark, the centre between the pulleys, upon the belt line, next set out at each end for the wood screws or bolts that are to hold the hanger plates, bore the hanger plates, and screw them up at one end, but not hard against the joists; leave $\frac{1}{2}$ in. or more for packing when levelling up; then set the plates at right angles across the joist, and mark the position of the joists so as to bore through the plates for the other screws which can be done by swinging the plates around, and without taking them down. Again set the plates across the joists as accurately as possible by means of a carpenter's square, and mark the holes on the joist for the remaining wood screws. In screwing up the plates they can be brought level by furrowing down on their top, with pieces of wood split in two or notched to accommodate the wood screws placed between the plates and the joist. To mount the hangers, if they have pivot bearings, as all ought to have, bore through the hanger plate for one bolt by measurement; no great accuracy is needed in this, unless the shaft has to come laterally to a particular line, which is seldom the case. Screw up one hanger with a through bolt, then remove the pulleys from the shaft, put it in the hangers, then prop the loose one, or both, if needed, with a brace resting on the floor, or on a stage, as shown in Fig. 2216. For the next operation, procure a pole or strip of wood, Fig. 2217, long enough to reach from the countershaft to the line shaft, cut a notch in the end, or drive a strong spike, *s*, in the side, and let it rest on the line shaft at L, and extend to the countershaft at C. By moving alternately from one end of the countershaft to the other, and driving the loose hanger to adjust it, a parallel is obtained much truer than by lines and measurement, and in a tenth part of the time: the pole can be marked at the centres of the countershaft at each trial until the ends correspond. Then bore the three remaining holes for the hanger bolts, put the pulleys on the shaft, and mount the whole in place. Level the shaft by using a plumb-line alongside the pulleys, which, if they are true, will be found a more accurate plan than to use a spirit level on the shaft itself. With a good pair of trestles at hand, and wood screws and hanger plates ready, an ordinary countershaft for belts from 3 to 6 in. wide should be put up in one and a half to three hours' time by one man and an assistant. The time of erecting, and the accuracy with which a shaft can be set, as well as the facility with which it can be kept in line, depend greatly upon how the hangers are made. If the bearings are pivoted, and arranged to be adjusted vertically on the hanger, it is but little trouble to keep shafts level. The bolt holes in the hanger plate, if slotted to allow for horizontal adjustment, will answer for pendent hangers without having the bearings movable in the brackets."

2215.

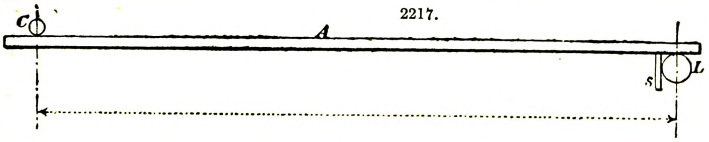


2216.



Couplings for shafts should be of such a nature that the strength and rigidity at the joint shall be as great, if not greater than at any other part of the line, so that if the line be subjected to flexure it will bend anywhere else than in the couplings.

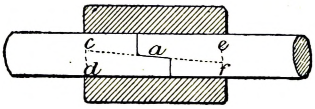
2217.



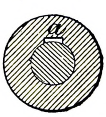
2222.

The solid half-lap coupling, shown in Fig. 2218, is recommended by Box as the best of all for small shafts up to 4½ in. or 5 in. in diameter, but for larger shafts they become very clumsy and heavy. This kind of coupling requires thoroughly good workmanship, especially in the fitting of the lap joint; the angle or level of the joint should be about 1 in. a foot, and may be conveniently described by striking the arcs *cd* and *ef* from the centre of the lap *a*, with a radius of 6 in., and setting off $\frac{1}{2}$ in. above and below the centre in the manner shown in the figure. The coupling box is of cast iron, and is secured in position by a hollow key, at the point *a* in the cross-section, Fig. 2219. One advantage in these couplings over many others is their safety; there are no projecting bolts, as in the flange coupling, to catch the dress of workmen or workwomen, or to become entangled with a strap which comes off accidentally; when turned and polished they are easily kept clean, and there are no bolts to shake loose in working.

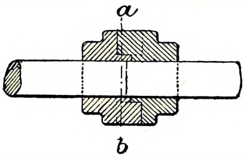
2218.



2219



2220.



2221.

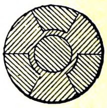
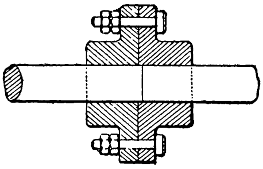


Table III.—Proportions of Solid Half-lap Couplings, with Cast-iron Boxes.

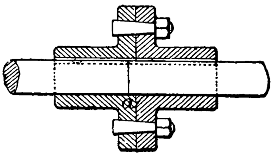
Diameter of Shaft.	Thickness of Metal.	Diameter of Coupling.	Length of Coupling.	Length of Lap.
ins.	ins.	ins	ins.	ins.
1	1	3	$5\frac{1}{4}$	1
$1\frac{1}{2}$	$1\frac{1}{2}$	$4\frac{1}{2}$	$6\frac{3}{4}$	$1\frac{3}{8}$
2	$1\frac{3}{4}$	$5\frac{1}{2}$	$8\frac{1}{4}$	$1\frac{3}{4}$
$2\frac{1}{2}$	2	$6\frac{1}{2}$	$9\frac{3}{4}$	$2\frac{1}{8}$
3	$2\frac{1}{8}$	$7\frac{1}{4}$	$10\frac{7}{8}$	$2\frac{1}{2}$
$3\frac{1}{2}$	$2\frac{3}{8}$	$8\frac{1}{4}$	$12\frac{3}{8}$	$2\frac{7}{8}$
4	$2\frac{1}{2}$	9	$13\frac{1}{2}$	$3\frac{1}{4}$
$4\frac{1}{2}$	$2\frac{5}{8}$	$9\frac{3}{4}$	$14\frac{5}{8}$	$3\frac{5}{8}$
5	$2\frac{3}{4}$	$10\frac{1}{2}$	$15\frac{3}{4}$	4

The claw coupling, shown in Figs. 2220 and 2221, is recommended by Box in his 'Treatise on Mill Gearing' to be used for all shafts above 6 in. in diameter; Fig. 2220 is a longitudinal section through the coupling, showing the shafts in position, and Fig. 2221 is a cross section on the line *ab*. When fitted together by clipping, in the usual way these couplings are very expensive, and require good workmanship, but the expense of this fitting may be entirely avoided by casting one half upon the other. In that case one half is cast in sand, and this casting being imbedded with the wooden pattern locked into it, another mould is taken from the pattern with the wood part in the cope, and the second half is cast upon the first. A perfect fit is thus obtained without labour, and the metal is chilled and wears longer, so that this form of coupling is the cheapest of any; the first half must, of course, be coated with founders' blacking where the molten metal of the second half comes in contact with it, to prevent adherence. The shrinkage will be sufficient to enable the two halves to be separated when necessary, but they should be locked together, and so bored to ensure parallelism. This kind of coupling requires to be well secured to the shaft by good sunk keys, as shown at *a*, Fig. 2220.

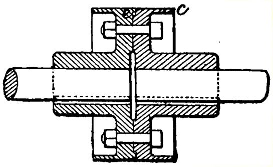
2223.



2224.



2225.



The flange coupling, Figs. 2223 and 2224, was at one time very generally adopted by American engineers in preference to the solid lap or claw couplings above described. For good work these couplings should be turned all over, and in any case the two internal faces must be turned to fit together accurately; the bolt holes must be drilled out truly to match one another, and the bolts must be turned parallel throughout, and fit well. To keep the two shafts in line with each other, one of them should enter the opposite half coupling, $\frac{1}{4}$ in. in the smallest sizes, $\frac{3}{8}$ in. in medium shafts, and $\frac{1}{2}$ in. in 6-in. shafts, and so on in proportion. This projecting end, or dowel *a*, forms a very serious objection to the use of these couplings, as when disconnecting a shaft it requires that the latter be moved endwise to the extent of the lap, and this is often a cause of much inconvenience, for if a long shaft is to be disconnected in the centre it not unfrequently happens that in order to move either part $\frac{1}{2}$ in. endwise several pulleys, wheels, or collars must be loosened, while if the couplings are placed against the bearings, as is often the case, such movement is rendered impossible. As these couplings depend for driving power entirely on the key, that part of the work must be well and firmly done; each half should be secured by a sunk key, as in Fig. 2220, driven from the inside, and cut off flush before the coupling is put together; and the face should be turned true in its place after the coupling has been keyed on the shaft, otherwise driving the key is apt to throw the coupling out of truth. Another objection to the use of these flanged couplings is on account of the danger arising from the exposed bolt heads and nuts. To obviate this danger, the coupling shown in Fig. 2225 was introduced. This coupling is provided with a guard rim, *c*, to prevent the danger of belts or clothing catching on the bolt heads or nuts; this rim gives a stronger form to the plates, so that the latter can be reduced in thickness and weight, while in many cases it also permits the couplings to be employed as pulleys for driving belts. The dowel is formed by a slight interlocking at the rim, as shown at *e*, in most cases not exceeding $\frac{1}{8}$ in. in depth, so that in disconnecting a shaft it rarely happens but that the supports by slightly straining the shaft will allow a section of the latter to be taken out.

The following table, giving the proportions for plain flanged couplings, is extracted from Box's 'Mill Gearing':—

TABLE IV.—PROPORTIONS FOR FLANGED COUPLINGS.

Diameter of Shaft.	Diameter of Flange.	Thickness of Flange.	Diameter of Boss.	Depth of Boss.	No. of Bolts.	Diameter of Bolt.	Diameter of Circle of Bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
1	5	$\frac{3}{4}$	$2\frac{1}{4}$	2	3	$\frac{1}{2}$	$3\frac{1}{2}$
$1\frac{1}{2}$	$6\frac{1}{2}$	$\frac{7}{8}$	$3\frac{1}{4}$	$2\frac{1}{2}$	3	$\frac{5}{8}$	$4\frac{3}{4}$
2	8	$1\frac{1}{16}$	$4\frac{1}{4}$	3	4	$\frac{3}{4}$	6
$2\frac{1}{2}$	$9\frac{1}{2}$	$1\frac{3}{16}$	$5\frac{1}{4}$	$3\frac{1}{2}$	4	$\frac{7}{8}$	$7\frac{1}{4}$
3	11	$1\frac{3}{8}$	$6\frac{1}{4}$	4	4	1	$8\frac{1}{2}$
$3\frac{1}{2}$	$12\frac{1}{2}$	$1\frac{1}{2}$	$7\frac{1}{8}$	$4\frac{1}{2}$	4	1	$9\frac{3}{4}$
4	14	$1\frac{5}{8}$	8	5	6	1	11
$4\frac{1}{2}$	$15\frac{1}{2}$	$1\frac{7}{8}$	$8\frac{7}{8}$	$5\frac{1}{2}$	6	1	$12\frac{1}{2}$
5	17	2	$9\frac{3}{4}$	6	6	$1\frac{1}{8}$	$13\frac{1}{2}$
6	20	$2\frac{1}{4}$	$11\frac{1}{2}$	7	6	$1\frac{3}{8}$	16

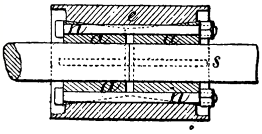
The objections to these forms of couplings are many. In the case of the solid half-lap coupling the bars to be united by it must be of absolutely equal diameter, or they will soon work loose; and the attainment of this accuracy is an expensive operation. Machines can readily be constructed to turn bars of round iron in the condition they come from the rolling mill to a nearly uniform size with a great rapidity, and at a very small cost. By nearly uniform is meant that when the shafts are tested by sliding over them a standard gauge they will be apparently of uniform diameter, but a careful measurement will show them to be only approximately alike in size. This commercial accuracy, as it may be termed, is easily obtainable by machines and by unskilled labour; absolute accuracy would involve more costly processes, and the utmost skill of the most experienced workmen. When flanged couplings are employed each half of the coupling has to be carefully and accurately fitted to the end of the shaft, and the couplings afterwards faced in the lathe, and the holes drilled for the bolts. This facing up prevents all shifting of couplings from one length of shafting to another, as they belong only where fitted; while as each half-coupling possesses its corresponding fitted mate, on account of the bolt holes, the whole length of shafting becomes a special machine, of which no portion is interchangeable or can be moved from the position for which it was fitted. Again, if these couplings have to be driven off two or three times for the purpose of changing pulleys, or for other reason, the fit will be altogether destroyed.

Adjustable or compression couplings, as already stated, are the only kind which should be used for line shafts; they are equally safe as any other system of coupling, for their failure can only result either from deficient strength in their proportions, or from very bad fitting; while the advantages arising from their use, such as a duplicating system, placing pulleys, and so on, are so apparent as to be self-evident. It may be further said that compressive couplings properly constructed do not cause one-tenth part as much delay and expense as those having a solid fit, and held on by means of wedge keys. In putting on adjustable couplings, they should be put on with a view to removal, all parts being well and carefully oiled so as to avoid all chances of their rusting fast. In order that these couplings may fulfil the objects with which they are designed, it is necessary that they should fulfil the following conditions:—

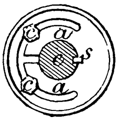
1. The coupling should act independently on each shaft, so that slight variations in the diameter of the shafts connected will not cause one to be more firmly gripped than the other.
2. The range of adjustment should be such as to suit the ordinary irregularities of diameter which must occur in turning shafts in an expeditious manner, and finishing at one operation.
3. The couplings should close concentrically upon shafts, or, as this is impracticable in a strict sense we may say, bear upon three or more points, the more extended such bearing the better.
4. They should be so constructed as to be instantly removable, and so that there will be no joints to stick fast by corrosion.
5. The strength of the coupling as to resisting either torsional or deflective strains should be at least one-half greater than that of the shafts connected.

The double cone coupling of Sellers and Co, Fig. 2226, consists of two cones *a*, bored to fit loosely on the shaft *s*; externally these cone plugs are turned to an exact taper, and fit within the external shell *c*, which is a plain cylinder of cast iron bored with a diminishing taper from each end. The cones *a* are drawn into the shell *c* by the through bolts *n*; these bolts are square to prevent them from turning when the nuts are screwed up, and they are let into the external shell *c*, in the manner shown in the figure, so as to constitute keys, which prevent the cones *a* from turning in the shell *c*, and by this means communicate the driving strain from one cone to the other, and from one shaft to the other. The cones *a* are split open on one side, and deeply grooved on the opposite side; this, with the slots provided for the bolts, renders the cones quite flexible, although their cross-section may be even greater than that of the shafts connected. The cones *a* being drawn in simply by the pressure of the bolts and nuts *n*, it is evident that one cannot be drawn into the sleeve *e* with any more force than the other, and consequently the pressure exerted on the ends of the two shafts must be equal; and therefore the shafts need not be of exactly the same size, in point of fact shafts of an appreciable difference in size may be as firmly held as if they were of the same diameter. When it is required to remove this coupling slack up the bolts, and if not then loose, a few blows upon the outer shell with a billet of wood will probably start it loose; or a wedge, such as a cold chisel, driven into the split in the inner cones always loosens the cones and frees the couplings. When this coupling was first introduced it was subjected to severe trials to test its utility. The experiment was made by coupling two shafts, which were placed on three bearings 10 ft. apart, the coupling being near to the middle one; and these hangers were so placed as to bend the shaft 1$\frac{3}{4}$ in. out of line. These shafts so coupled were then made to revolve at the speed of 250 revolutions a minute for many weeks during working hours, and yet the coupling did not loosen under this severe strain.

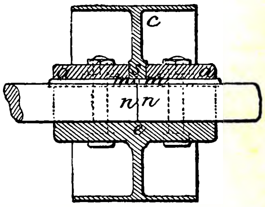
2226.



2227.

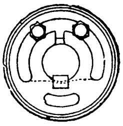


2228.

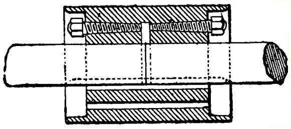


The coupling shown in Fig. 2228, and manufactured by Richards, London, and Kelly, Philadelphia, deserves notice on account of its simplicity and the small cost of its construction. Two strong semicircular caps *a* are bolted over the shafts in the manner of a common journal bearing; the lower shell *e* being continuous, and formed solid with the pulley *c*. The centre flange of this pulley is thickened up at *s*, so that the two ends *n* of the shafts are dowelled in this part, and the keys *m* are fitted in the caps, so as to be firmly gripped by any bending of the latter, and also more readily to permit them to spring slightly to accommodate any irregularities of size in the shafts. The caps are made either of malleable or cast iron as circumstances may require. The external pulley *c* can be made of any size to suit the purpose of driving machinery, and at the same time serves to shield the bolts and guard against danger; so that in estimating the cost of these couplings the value of a pulley can in most cases be deducted, leaving the coupling to be computed as the extra iron in the bosses, and the additional fitting required over boring and keying a common pulley.

2229.

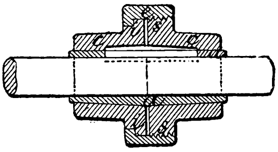


2230.

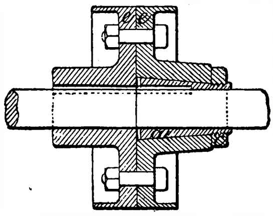


In Fig. 2227 is shown an end view of Cresson's patent coupling, which, like those already described, acts independently on each shaft. The sectional shell *a* is divided transversely in the centre of the coupling, and is forced upon the shaft *e* by means of the screws *c*, which are long and tapered. The shells *a* being split on one side, are sufficiently flexible so that when the screws *c* are driven in there is a strong grip given at these points on the shaft. The solid portion at *s* affords a firm seat for keying; the cored section extends through the coupling.

2231.



2232.



Charlton's shaft coupling, Figs. 2229 and 2230, is very similar to the above; it consists of a casting of a cylindrical form externally, and cored out in the manner shown in the end elevation, Fig. 2229. This casting is bored and has a key way cut in it, and the inner portion is then cut through opposite the key way. After being placed on the ends of the two lengths of shafting to be coupled, which shafts it may fit freely, it is tightened by screwing in the tapered bolts shown in the longitudinal section, Fig. 2230; these bolts cause the inner portion of the casting to clip the shafts firmly. The key *a* is only a carrier, and requires no fitting by hand, while the bolts *b* merely act as wedges, and are not subject to any other tensional strain; and further as the two bolts at the one end of the coupling act quite independently of those at the other, there is no necessity that the two lengths of shafting connected by the coupling should be of precisely the same diameter.

Both these couplings last described are very simple and easy to manufacture, and they have been thoroughly tested with very satisfactory results. This system may also be adopted for fixing pulleys to shafts, for which purpose it is equally advantageous.

John Richards' coupling, Fig. 2231, belongs to the class of couplings in which a continuous sleeve is employed, and which act independently on each shaft only to the extent of the flexibility of the said sleeve. In this coupling the sleeve or shell *a* is made thin and flexible to such an extent as to permit an independent action more or less complete on each shaft; *c* are two strong conical thimbles which are drawn together by the ring collar *e*, provided with screw threads at *s*. The thimbles *c* could not of course be drawn up sufficiently firm by means of the ring collar *e*, because of the friction of the screw *s* and of the joint at *i*; so that in applying the coupling the thimbles *c* are driven on by blows until the tension is thought sufficient, and the collar *e* is then screwed up as firmly as possible. It will be seen at once that the strength of this coupling to resist transverse strains depends on the shell *a* alone, but it is also evident that unless the thimbles *c* move on the sleeve *a*, the ring collar *e* must be regarded as a firm connection between the shafts, and capable of resisting bending strains the same as a common flange coupling, except that the neutral axis will be in a different position.

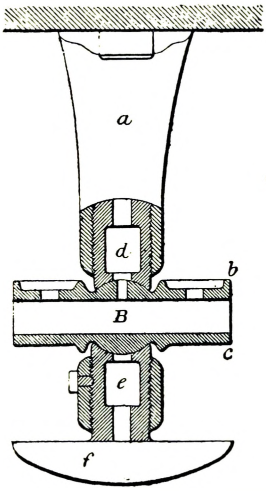
Another of Richards and London's ingenious couplings is shown in Fig. 2232. One half of this coupling consists of a common flange, keyed on in the usual manner; the other half is compressive and adjustable. The advantages claimed for this coupling were, that for each section of a shaft one end could at once be freed, so as to put on pulleys, or for any other purpose. As the arrangement does not, however, admit of interchange from one shaft to another, and as each coupling has to be fitted to its place the same as when two common flanges are employed, this coupling has not met with much favour. The shell *a* is conical, and split open on one side; a screw collar *c* draws the cone *a* from the centre, causing it to grip the shaft with great force, while, by loosing the collar *c*, the cone shell *a* can be driven back to release the shaft, which can then be withdrawn, if there is sufficient room, without disconnecting the two flanges *e*.

Next in importance to the proper means for uniting the various lengths composing a line shaft, come the support for the same. When shafting is suspended under the ceiling of a room, it is provided with what are called hangers; when it passes near to posts these hangers are changed in form and are called post hangers; and when it passes over the tops of beams or near to the floors, it is carried on what are called pillow blocks. All these devices have certain parts in common, namely, a journal box or bearing to receive the shaft, and some kind of frame to support and carry this box. As has been already pointed out, all bearings for line shafts should be pivoted and adjustable.

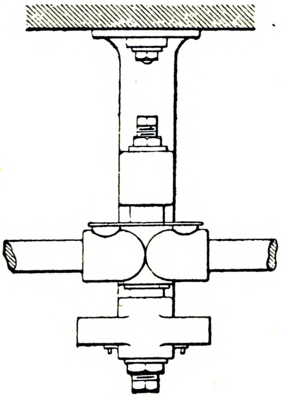
Pivoting secures a fit of shafts in their bearings which is altogether unattainable with rigid bearings under the ordinary circumstances attending the erection and setting of shafts; and as they ensure a fit of the shafts under all circumstances, pivoted bearings can be made long, and of hard metal, as already advocated. The difference in expense between erecting and adjusting a set of bearings for a line shaft which are pivoted and adjustable, and a set which are rigid, is very great; it being no uncommon thing to spend as much time in setting one rigid bearing as would have served to fix ten if the bearings had been pivoted and adjustable. If a bearing is formed rigid with a bracket, or bolted rigidly, which is the same thing, the adjustment of a fit between a shaft and its bearings is transferred to the connection between the brackets and the wall, post, foundation, or whatever they are mounted on, and all the nicety of a running fit must be attained in setting such brackets; there is not only the difficulty of lateral adjustment in erecting rigid bearings, but that of the axial adjustment as well; one is continually interfering with the other, and for several men to spend a whole day in fixing and adjusting a single bracket is no uncommon occurrence; while by having bearings pivoted and adjustable, the fixing of hanger or bracket plates becomes an easy and inexpensive matter, and precision is attained by adjusting the bearings after the brackets are bolted fast. The adjustment of bearings has, however, its chief importance in the maintenance of shafts; for freedom from accidents and reduction in repairs of line shafts, depend on their being kept in line, presuming of course that they are of proper size and well fitted; and if the bearings of a shaft can be adjusted vertically by means of screws, it is so simple and inexpensive an operation to level such a shaft that it may be performed at regular intervals, at a nominal expense and without the least detention, and thereby avoid the danger of accidents to the shaft, its couplings or bearings. The cost of maintenance, represented by lubrication, repairing, detention, &c., is considerably reduced by the adoption of pivoted bearings. When a bearing is formed of material as hard as cast iron, and with surface sufficient to prevent abrasive wear, which may be the case when such bearings are pivoted, oil may be used over many times and retain its lubricating power; while with short rigid bearings of soft metal, oil when once used is wasted, because loaded with metal dust. By using oil over several times it is not meant that the drippings may be caught and again poured on a bearing, but that oil contained in a reservoir can be fed to a bearing, and by the motion of a shaft be circulated until the lubricating property of the oil is exhausted; the amount of oil consumed in the bearings of line shafts, when applied in this manner, is rarely more than one-fifth part as much as will be consumed and wasted if poured on at intervals and be permitted to run off and be lost because too foul to be used a second time. In respect to repairing, it is evident that bearings which do not wear will not require renewal, and that bearings which keep in line will avoid those conditions which lead to derangement and detention.

In Fig. 2233 is shown a section of a hanger constructed on the ball and socket principle. Part of the frame of the hanger is represented at *a*, *b* is the top box, *c* the bottom box; these two form the journal box or bearing B, in which the shaft rotates. This box is provided, top and bottom, with spherical surfaces, so placed as to be in reality portions of a sphere which has its centre in the centre of the axis of the box B; *d* and *e*, called the plungers, are screwed into the frame, and are provided with cup-shaped ends to clasp the spherical parts of the box; and in these cup-shaped ends the box B can rock to a limited extent in every direction. The screwed plungers *d* and *e* serve a double purpose; first, of providing the socket for the sphere to roll in, and secondly, to permit of a vertical adjustment of the entire box to bring them in line, one with the other. At *f* is an oil dish to catch the drippings from the box. It is quite evident that a shaft placed in such a bearing will control the positions of the box, and will press uniformly over the entire length of the box. Figs. 2234 and 2235 are a front and side elevation of a suspension bracket or hanger; Fig. 2236 is a post hanger or wall-bracket; and Figs. 2238 and 2237 are front and side elevations of a pedestal bearing; these are all pivoted and adjustable bearings, constructed on the above principle by Richards and Atkinson, of Manchester.

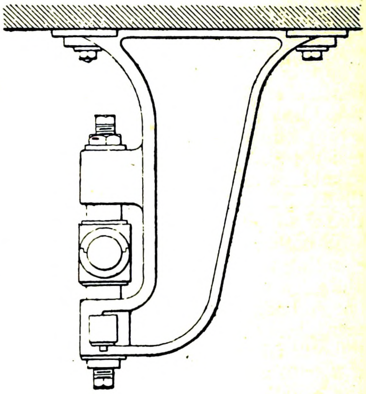
2233.



2234.

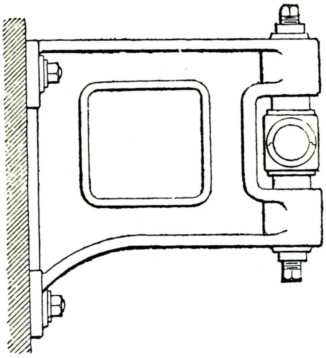


2235.

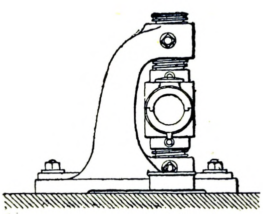


In Figs. 2239 and 2240 is indicated a plan of pivoting for what are known as open brackets; the supporting bracket of this bearing is not shown in the figures, which are merely diagrams to show the construction and action. In a vertical plane the bearing moves on the pivot at *a*; the stem *e* providing for the other movement in a horizontal plane. Lateral and vertical adjustment, within certain limits, is secured by means of the set screws at *m* and the ring-nut *n*.

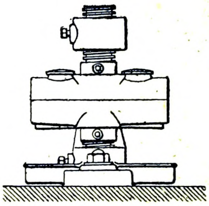
2236.



2238.



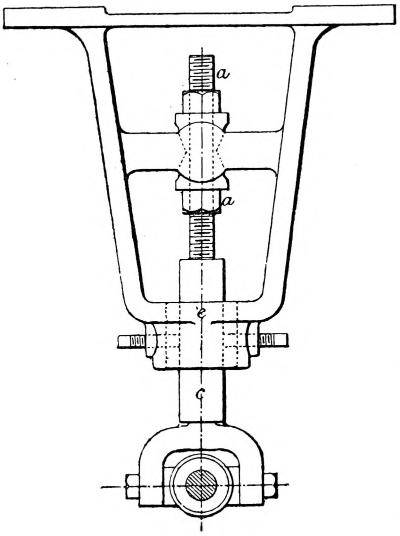
2237.



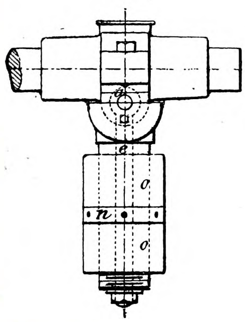
A method of constructing a pivoted and adjustable hanger for countershafts, and one which, in practice, has some advantages not common to such hangers, is that in Fig. 2241. The means of pivoting and adjusting the bearing will be readily understood from the drawing, except as to the long range of vertical adjustment. This last feature is an expedient to regulate the tension of belts coming down to machines such as lathes. The principal object, however, is to avoid coupled joints in the cone belts of lathes; with hangers constructed in this way, a lathe belt can be endless, made in one piece, and the tension be regulated at will; as the belt stretches the hangers can be set up by turning the nuts at *a*, care being taken to adjust both ends of the shaft the same. The bracket frame is cored out at *e*, large enough to permit a lateral adjustment of the stem *c*, so as to keep the countershaft in line with the main driving shaft.

Crane's adjustable and pivoted bracket, with self-lubricating bearing, is shown in Figs. 2242 to 2244; Fig. 2242 is a side elevation, Fig. 2243 a section on the line *a b*, and Fig. 2244 a plan view of the bottom half of the bearing showing the cradle C in its place. The journal bearing B is connected with the hanger or bracket H by means of the pendent swivel-pin P, and is thus capable of turning horizontally on a vertical centre; this swivel-pin is cast in one with the upper half of the bearing B, and is adjusted vertically by means of the screw-nuts S. The upper half of the bearing B is formed with a flange, at about the middle of its length, to receive the coupling screws *s*, which secure the two halves of the bearing B together. In the lower half of the bearing B is supported, upon half-round trunnions *c c′*, a cradle C, which is thus free to adjust itself vertically to the position of the shaft which it carries. The cradle C is of brass, and lined with soft metal, but would evidently be better if made of cast iron, for the reasons already pointed out. At the bottom of the cradle C is a projecting tube *d*, which dips into the oil-well D, formed in the bottom half of the bearing B. The tube *d* forms a conductor for the oil, which is caused to rise

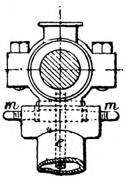
2241.



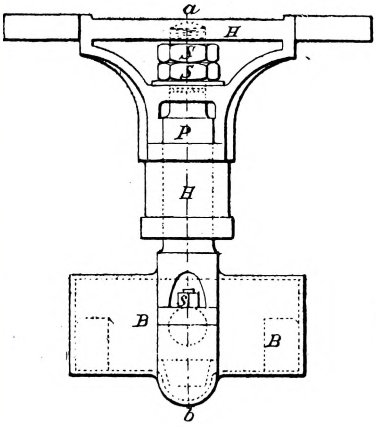
2239.



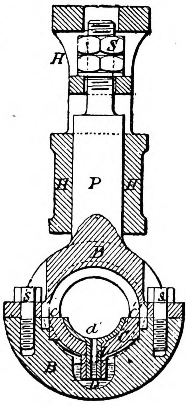
2240.

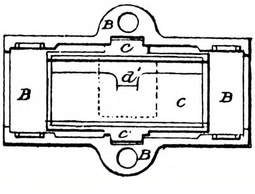


2242.



2243.



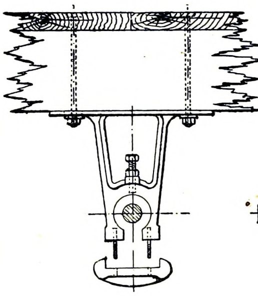


2244.

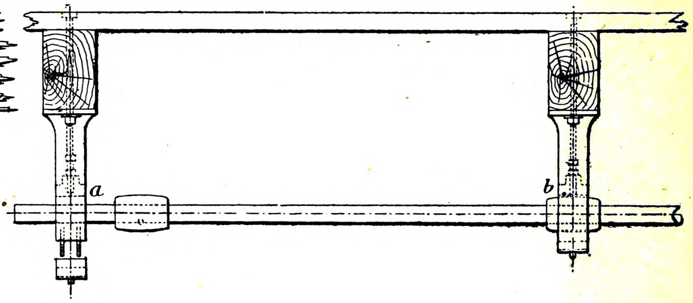
automatically from the reservoir D, and spread itself over the bearing-surface of the cradle C, by the following means: one side of the tube d is chamfered or recessed, as at d', and thus the shaft, when driven, produces a partial vacuum in the tube, and causes the oil to flow up from the reservoir, and so to lubricate the rubbing surfaces.

Vollrath's improved hanger for line shafts is shown in Figs. 2245 to 2248; Fig. 2245 is an end elevation, Fig. 2246 is a side elevation showing the shaft in position, Fig. 2247 is an enlarged view of the bottom part of the hanger, and Fig. 2248 is a vertical section through the centre of the last figure. The object of this invention is to facilitate the placing of shafts, the removal of them for any cause, and the replacing of them without interfering with the position of the bracket or hanger in which they are suspended. The hanger A is formed with a circular opening S in its lower part for the reception of the journal-box or brass B; a slot R is also formed in the lower part of the hanger to allow the entrance of the shaft into the opening S. The box B has formed on its under side two convex projections c, which are separated from each other by an angle of about 60°, and when inserted in the opening S, it is held in position by a set screw C, which engages in a countersunk recess formed in the outer surface of the said box. To strengthen the slotted part of the hanger, and prevent its spreading by the wedge-like action of the projections c on the inclined sides of the opening S, a clamping cover D is attached to the hanger by the screws G. The hanging of the shaft in its bearings is accomplished as follows: The boxes B having been slipped on the shaft, the latter is passed through the slot R, as at a, Fig. 2246, and the clamping covers D are attached to the hangers; the boxes B are then slid along the shaft, and brought into their proper positions in the openings S, and fastened in place by the set screws C, as at b.

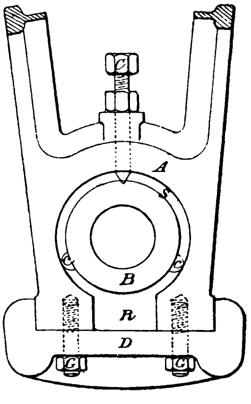
2245.



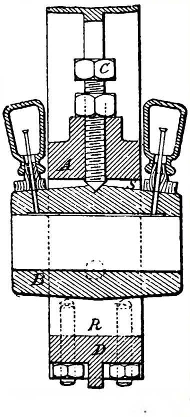
2246.



2247.



2248.

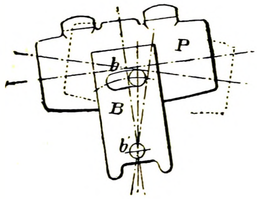


Smith and Coventry's patent adjustable hanger, Figs. 2251 to 2253, consists of a frame-casting A, having a planed vertical surface, to which is bolted the bracket B by means of two bolts $b\,b'$; the lower of these bolts, b', acts as a pivot upon which the bracket B can swing laterally within suitable limits, the hole through which the upper bolt, b, passes, being elongated to allow of this play. At the bottom of the frame A is a set screw s, by means of which the bracket B is adjusted vertically. The pedestal P is seated on the bracket B, and is held securely down to the same by the bolt c; in the centre of the underside of the pedestal is formed a turned projection o, upon which the same swings radially, thus affording a delicate adjustment to the shaft, and ensuring perfect contact without the use of packing. The bearing surface in this hanger is of cast iron, and is four diameters in length; one oil-cup and two tallow-cups, one on each side, supply constant lubrication.

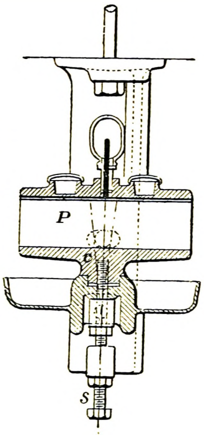
The following method of adjusting a line shaft is given by Joshua Rose in a paper in 'Engineering':—

"First, prepare a number of frames, Fig. 2252, called targets. These are formed of pieces of wood nailed together, with the outer edge face planed true, and having on one side a line marked parallel with the planed edge, and about ¾ in. distant from it. This line is intended for use as a guide in conjunction with the plumb line B. The next proceeding is to stretch a line vertically, parallel with the line of shafting, but sufficiently below to clear the largest hub of any of the pulleys upon it, as shown in Fig. 2253, in which A represents the shafting, B the largest pulley hub, and C the stretched line. In adjusting this line, however, we have the following considerations: If the whole line of shafting is of one diameter, the line C is set equidistant from the shafting at each end; but if one end of the shafting is of larger diameter than the other, the line C must be set further from the surface of the shafting, at the small end, to an amount equal to one-half of the difference in the two diameters; and since the line is sufficiently far from the shafting to clear the largest hub thereon, it makes, so far as stretching the line is concerned, no difference of what diameter the middle sections of shafting may be; the line should, however, be set true, as indicated by a spirit-level.

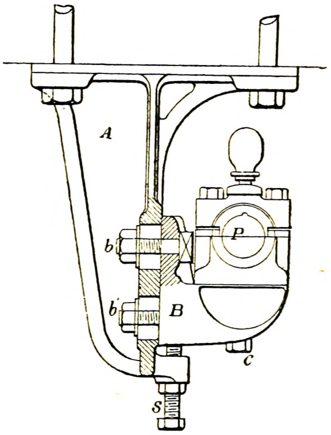
2251.



2250.

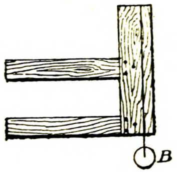


2249.

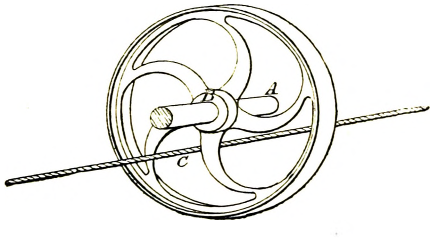


"The next proceeding is to erect the targets as follows: The planed edge is brought true with and barely touching the stretched line, and is also adjusted, so that the plumb line B, Fig. 2252, will stand true with the line, and when so adjusted, the target is nailed to the post carrying the shaft-hanger. In performing this nailing, two nails may be slightly inserted, so as to sustain the target, and the adjustment made by tapping the target with the hammer, and the nails then driven home, the operator taking care that driving the nails does not alter the adjustment; in Fig. 2254, A is the line of shafting, B are two of the hanger-posts, and C two of the adjusted targets. Having adjusted and fixed, in the manner above described, a target to each of the posts supporting a shaft-hanger, remove the horizontal stretched line C, Fig. 2253; then take a wooden straight-edge, long enough to reach from one post to another, and beginning at one end of the shafting, place the flat side of the straight-edge against the planed edge of two targets, at a distance of about 15 in. below the top of the shafting, and after levelling the straight-edge with a spirit-level, mark a line on the planed edge of each of the two targets, even with the edge of the straight-edge; move the straight-edge to the next pair of targets, placing the edge even with the mark already made on the second target, level the straight-edge with a spirit-level as before, and mark a line on the third target; and continue this process until a straight and horizontally level line has been marked across all the targets. This operation is shown in Fig. 2255, in which A is the line of shafting, B one of the hangers, and C the targets; D shows the line on the first target, and E the line on the second; F is the straight-edge, levelled ready to form a guide whereby the line D may be carried forward, level and straight to target three, and so on across all the targets. The line thus marked is the standard whereby the shafting is to be adjusted vertically. For the purpose of this adjustment take a wooden square, Fig. 2256, the edges A and B of which are true and at a right angle to each other. The line marked across the targets D, Fig. 2255, being 15 in. below the centre line of the shaft at the end from which it started, mark upon the square, Fig. 2256, the line C, 15 in. from the edge A. To adjust the shaft for vertical height, apply this

2252.



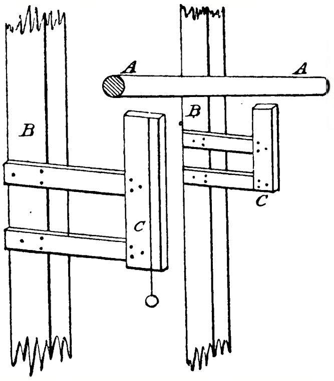
2253.



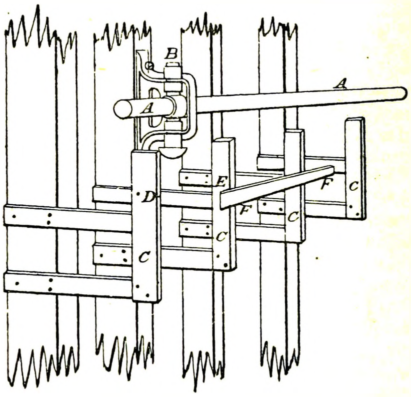
gauge at each of the targets in the manner shown in Fig. 2257; and it is evident that the shaft will be set exactly true, when the mark C on the square comes exactly fair with the lines D marked on the targets. For horizontal adjustment, place a straight-edge along the face of each target, and adjust the shaft equidistant from this straight-edge, as shown in Fig. 2258, in which A is the shaft, B the target, C the straight-edge, and D a gauge, or distance piece. If these two gauges are applied at every target, and the adjustments made, as shown in Figs. 2257 and 2258, the whole line of shafting will be set level and true.

"There are, however, several points during the latter part of the process at which consideration is required. Thus, after the horizontal line marked on the targets by the straight-edge, and used for the vertical adjustment, has been struck on all the targets, the distance from the centre of the shafting to that line should be measured at each end of the shafting, and if it is found to be equal, we may proceed with the adjustment; but if, on the other hand, it is not found to be equal, we must determine whether it will be well to lift one end of the shaft and lower the other, or make the whole adjustment at one end by lifting or lowering it, as the case may be. In coming to this determination we must bear in mind what effect it will have on the various belts in making them too long or too short; and when a decision is reached, we must mark the line C on the gauge, Fig. 2256, accordingly, and not at the distance represented in our example by the 15 in.

2254.

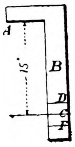


2255.

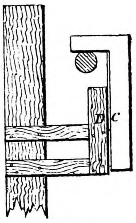


"The method of adjustment thus pursued possesses the advantage that it shows how much the whole line of shafting is out of truth before any adjustment is made, and that without entailing any great trouble in ascertaining it; so that, in making the adjustment, the operator acts intelligently, and does not commence at one end utterly ignorant of where the adjustment is going to lead him to when he arrives at the other. Then, again, it is a very correct method, nor does it make any difference if the shafting has sections of different diameters or not, for in that case we have but to measure the diameter of the shafting, and mark the adjusting line C, Fig. 2256, accordingly, and when the adjustment is completed, the centre line of the whole length of the line of shafting will be true and level. In further explanation, however, it may be well to illustrate the method of applying the gauge, Fig. 2257, and the straight-edge C, and gauge D, Fig. 2258, in cases where there are in the same line sections of shafting of different diameters. Suppose, then, that the line of shafting has a mid-section of $2\frac{1}{4}$ in. in diameter, and is 2 in. in diameter at one end, and $2\frac{1}{2}$ in. at the other. All we have to do is to mark on gauge, Fig. 2256, two extra lines, D and E, the distance between C and D, and also between C and E, being $\frac{1}{8}$ in., that is half the amount of the difference in diameters; then if the line C was at the proper distance from A for the section of $2\frac{1}{4}$ in. diameter, the line D will be at the proper distance for the section of 2 in., and E at the proper distance for the section of $2\frac{1}{2}$ in. in diameter. In like manner, for the horizontal adjustment, the gauge piece D, Fig. 2258, would require, when measuring the $2\frac{1}{4}$-in. section, to be $\frac{1}{8}$ in. shorter than for the 2-in. section, while for the $2\frac{1}{2}$-in. section it would require to be $\frac{1}{8}$ in. shorter than that used for the $2\frac{1}{4}$-in. section, the difference again being one-half the amount of the variation in the respective diameters. Thus the whole process is simple, easy of accomplishment, and very accurate.

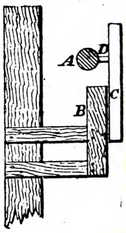
2256.



2257.



2258.



"If the line of shafting is suspended from the ceiling instead of from uprights, the method of procedure is the same, the form of the targets being varied to suit the conditions. The process only requires that the faced edges of the targets shall all stand plumb and true with the stretched line. It will be noted that the plumb lines B, Fig. 2252, are provided simply as guides whereby to set the targets, and are put at about $\frac{3}{4}$ in. inside of the planed edges, so as to be out of the way of the stretched line. It is of no consequence how long the stretched line is, since its sag does not in any manner disturb the correct adjustment."

The flexible shaft is of great service for such purposes as transmitting power to or from an ordinary shaft to many tools, as drills for boiler work, brushes for fettling castings, and the like. As now constructed the flexible shaft is made up of a core, a case, and appropriate fittings by which the two are joined, and rotary motion communicated to one end of the shaft and delivered at the other.

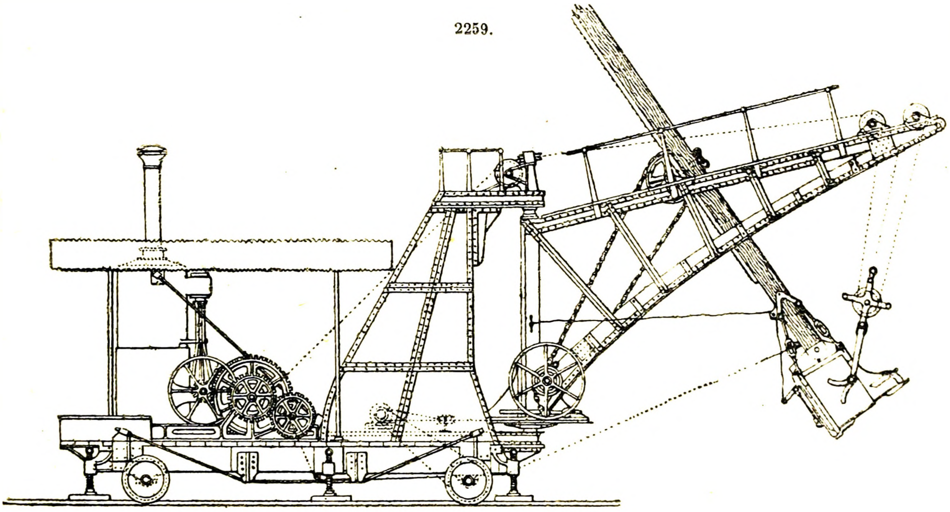
The core is composed of a series of concentric steel wire coils wound hard on each other, the direction of the pitch changing with each layer. The pitch direction of the outside layer is such that the latter will tend to contract under strain, the shaft always running one way. The case is made of a hollow coil of square wire, with a slight groove on the outer side. The coil is covered with leather, the office of the groove in the wire being to prevent the leather from slipping. The inside diameter of the case is slightly larger than that of the core, and the ends are furnished with iron ferrules to receive the driving pulley and the head-piece carrying the working tool.

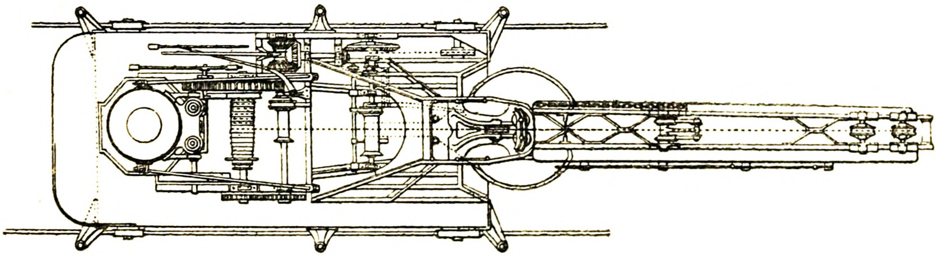
If a piece of core be mounted in bearings, and curved excessively, it will soon begin to heat, if set in motion, and will finally break. This contingency is provided for by making the case sufficiently rigid to prevent bending beyond the safe limit. There is some slight rubbing action between the wires of the inner and outer coils, but the effect of this is so slight as to be imperceptible, even in shafts that have been a long time in service. The other frictional elements are those common to all machines, the wear of the journals and their bearings, and the wear of the outer layer of the core at points of contact with the case.

STEAM NAVVY.

Figs. 2259, 2260 are of a steam navvy, by Ruston, Procter and Co., consisting of a rectangular truck, supported on four wheels, carrying the engine and boiler, wheel gear, fixed post, and jib. The engine is vertical, of 10 H.P., two cylinders, and gives motion by a pinion upon its crank shaft, to the main spur wheel upon the main hoisting drum shaft, from which the motion is communicated to the drum for swinging the jib, and the drum for drawing the bucket back. The drum for swinging the jib has a reversing friction motion for swinging both ways. The bucket handle is regulated by hand wheel and chain pinion, which give motion to a pinion at the top of the jib, gearing into a rack upon the bucket handle. The truck is provided with six strong screws, or lifting jacks, for the

2259.





2260.

purpose of steadying and taking the whole weight of the navvy when at work. The jib which carries the bucket handle is constructed entirely of plate iron, and strengthened with angle iron, as also is the fixed post and truck. At the bottom of the fixed post is a water tank for supplying the boiler. The bucket is of plate iron, and fitted with four steel pointed teeth, and a sharp steel nose where it first enters the ground. Improved propelling gear is also provided for moving the machine along the rails by a self-acting arrangement of reversing tooth gear, which communicates the motion to the front axle by an endless chain. A corrugated iron roof covers the engine, and the whole of the working parts, except the jib gear.

In an account of some work executed by this machine, in the Min. Inst. C.E. vol. lii., the dimensions of the cutting to be excavated were 30 ft. wide at the base, slopes 2 to 1, greatest depth 22 ft., smallest depth 12 ft., length about 15 chains, contents about 45,000 cub. yd.

The navvy is placed upon the formation level of the cutting, on two lengths of large flat-bottomed rails, laid upon sleepers 12 in. by 6 in. deep, about 2 feet apart. A tramroad for empty waggons follows up the centre line behind the navvy, and there is a road on each side the machine for filling waggons, parallel to the centre road, but at a level of about 3 ft. above formation. The waggons have to be brought up to a position at right angles to the centre line of the machine, and directly under the bucket for filling. The bucket describes a radius of about 20 ft., thus requiring a width of working room exceeding 40 feet across the cutting. This is secured by taking advantage of the slopes at the false level. The roads are connected at the mouth of the cutting by points, and close behind the navvy by jumps, so that all returned empties are passed up the centre road, and supplied to each side alternately by horses through the jump. When filled they pass out down the side road to form a train at the mouth of the cutting. In this way two waggons can be filled in a few seconds over five minutes. The process of getting the earth by the machine bucket may be best described as paring the surface from the bottom to the top in a series of strips, about 4 in. or 6 in. deep, from the centre of the cutting to each side waggon, in the form of a basin, resembling the inside of a conchoidal shell. The man at the wheel regulates this motion, and may show great skill or otherwise in its guidance, as the more regular the action the less is the wear and tear of the machinery. When the bucket reaches the top, the driver jibs round to the waggon, drawing slightly in from the face by another motion at the same time, and directly the bucket is over the waggon the wheel man pulls a string connected with a catch to the trap-door, or lid, at the bottom of the bucket, and the contents fall into the waggon. The catch-man refastens the catch, having previously thrown back any lumps which roll in its way, and the bucket returns and drops to the ground for another slice. Men in the gullet and on the slopes constantly cut out the little corners, which lie outside the basin or bucket radius. This is continued until the face becomes too far advanced for the bucket to reach, when the whole machine is moved onward by screwing up the jacks, pulling the rails forward, lowering it down again on its wheels, and the navvy then advances by its own locomotion to the position necessary for a fresh start, an operation which usually occupies about ten minutes. This moving of the machine requires to be done about four or five times a day, and at the close of a good day's work in a cutting, the navvy will be about 6 ft. in advance of the position in the morning.

Generally the harder and tougher the stuff, is the greater is the saving over hand labour. To suit the different materials the same-sized machine has been supplied with buckets of from 1 yd. to nearly 2 yd. capacity, the most useful size being the 1 yd. The working face may be as much as 20 to 25 ft. deep, the deeper the better, other things being equal, as then less proportionate time is lost in moving forward the machine. In this case also the kind of material fixes the most economical depth to work at. Cuttings in which there are two waggon tracks will give a much better result than those in which there is only room for one track, there being less delay in bringing up the waggons, and a less average distance swung round by the jib. The last objection applies also to machines working a longitudinal face, when more time a day is occupied in moving forward, owing to the jib having but two-thirds the range of cut that it has when working in a gullet, excavating one-third less material between each forward movement, and necessitating a forward movement more frequently, in the proportion of 3 to 2, an important item in the long run. It is almost superfluous to add that the greater the content of the excavation the more profitable is the return, less time and money being expended proportionately in fixing and getting the machine to work.

In conclusion, the advantages of the steam navvy may be summed up as follows. It will excavate and deliver into waggons 500 to 600 cub. yd. of stuff a day. It is suitable for any kind of material, from sand and gravel to the toughest clay. It will turn out work requiring fifty to sixty navvies to accomplish by hand. It can readily be handled by two men and a boy. It effects a great saving in time, and can be quickly set to work in situations where it would be difficult to get the requisite hand labour, and till more so to keep together a large body of men.

STEEL.

In the ordinary Bessemer operation, when the flame drops, as observed by the naked eye, or when the carbon lines disappear, as more accurately observed through the spectroscope, there still remain in the metal some hundredths of a per cent. of carbon, silicon, and all the phosphorus which the metal originally contained. Further blowing would oxidize the iron itself. But if the slag in the converter, instead of being acid, chiefly silica, as in the ordinary operation, is basic, chiefly lime, a small part of the phosphorus will be found in the slag, instead of in the metal, when the flame drops. And if the blowing is further continued for two or three minutes, all the phosphorus, excepting a few hundredths, will be found in the slag, and the iron will not have been much oxidized; it will have been protected by the phosphorus. Chemists disagree as to the precise reactions which occur. It is supposed that phosphorus is always oxidized by the air blast, and that it constantly returns to the iron in presence of an acid slag. It is certain that a basic slag retains the phosphorus, however it may have obtained it. The basic process, therefore, consists of two things—the maintenance of a basic slag, and the afterblow.

The basic slag is formed by the addition of about twenty per cent. of lime to the iron charge in the converter before or during the blowing. The basic slag is maintained chiefly by making the converter lining of lime, and also by using iron low in silicon. An acid lining would be destroyed by the lime additions, and would vitiate the slag. The latter result would be produced, also, by silica formed by the oxidation of the silicon in the iron. The difficulty has been the limited durability of the basic lining. After much experimenting, practicable linings have been made of dolomite bricks formed by wetting and moulding pulverized magnesian limestone, and then burning at the highest attainable temperature. The magnesia prevents the bricks from crumbling when exposed to the air. Linings are also formed by ramming hard-burned, pulverized dolomite, mixed with ten per cent. of tar, into the converter. Ordinary firebrick tuyeres are used in lime bottoms, or the bottoms are rammed around rods which form tuyere holes.

The afterblow presents little difficulty; its duration is soon determined for any grade of material and products.

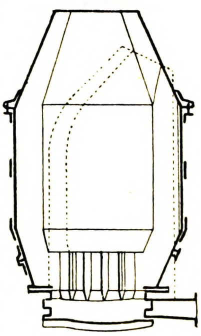
In order that the phosphorus may be thoroughly removed, there must be plenty of it. Silicon, the chief heat-giver in the ordinary process, must be kept low. Phosphorus is also a heat-giver, but there must be enough of it to maintain, by its combustion, perfect fluidity in nearly pure iron. At a lower temperature the Bessemer process could not be completed. Iron best adapted to the basic process has 2 to 2½ per cent. of phosphorus, and under 1 per cent. of silicon, also 1½ to 2½ per cent. of manganese—a heat-giver and a valuable ingredient in steel; but the manganese may be dispensed with at this stage of the operation. The afterblow completely removes the silicon and reduces other impurities.

Spiegeleisen, or ferro-manganese, are added to the blown metal, but most of the slag is first poured out of the converter, so that the manganese shall not carry the phosphorus out of the slag to the iron. Otherwise the process is conducted in the usual manner.

The practical success of the basic process is chiefly due to the researches of S. G. Thomas and P. G. Gilchrist. Their early method of working was to charge the additions of oxide or iron and lime at the same time into the converter, and pour the molten lead upon them. The quantity of additions varied from 15 to 25 per cent. on the metal charged, according to the amount of silicon in the pig iron used, but it was soon found that the oxide of iron was unnecessary; besides, it cooled the bath of metal, and lime additions only are required. After about three minutes' underblow, a sample of metal was taken, and when the bath was sufficiently dephosphorized to give a soft ductile metal, the spiegel was added.

William Richards, who has had much experience with the process, described, in 1880, some converters at the Cleveland Steelworks of a size and form which he expected would enable him to overcome some of the difficulties experienced when working with the old converters on the basic system. Fig. 2261 shows the form and size of the converter adapted. It is concentric, whilst the old converters are eccentric. During the operation of blowing, the lime and metal are lifted by the force of the blast, and when that force is somewhat expended the materials fall again on to the bottom in the new form, whilst in the old form some portions would cling to the nose. The concentric form has also another advantage; it gives a much larger area of floor to work in by enabling the metal to be poured into the converter when turned on its side with the nose pointing away from the converter ladle crane, just the reverse of the present practice. In Richards' plan of operation the converter is first heated up with coke, so as to prevent the chilling of the metal. Then a measured quantity of well-burned lime, about 16 per cent. of the weight of molten metal mixed with a small quantity of coal or coke, is charged into the converter, and blown till the lime is well heated. The molten metal is then poured on the lime additions, the blast of 25-lb. pressure is turned on, and the carbon lines disappear in about ten minutes; then after about two and a half minutes' overblow, the converter is turned down, and a small sample quickly made, which is beaten into a thin sheet under a small steam hammer, cooled in water, broken in two pieces, and the fracture shows whether the metal is sufficiently ductile. If it is not so, then the blowing is prolonged, after which the usual spiegel is added, being poured into the ladle, not into the converter. In order to work economically, the metal should be taken direct from the blast furnace, so as to avoid the cost of remelting in a cupola, and to avoid further contact of the metal with the sulphur and impurities of the coke. It is not an easy matter to accomplish in a blast furnace the manufacture of a metal low in silicon and at the same time low in sulphur. Richards has succeeded in making a mottled Cleveland iron with 1 per cent. of silicon and ·16 sulphur, and white iron with ·5 silicon and ·25 sulphur, which, taken direct from the blast furnace, have both made excellent steel. There is, however, another method of operating which obviates the necessity of making a particular quality of Cleveland pig iron. In the transfer system grey iron is taken direct from the blast furnace to the converter without any consideration as to the percentage of sulphur, which is always low in grey iron. This grey metal is poured into a converter with a silicious lining and desiliconized, when, after twelve or fifteen minutes' blowing in the ordinary manner, it is poured out of the converter into the ladle, and poured again from the ladle into a converter lined with dolomite, taking care that the highly silicious slag is prevented from entering the basic-lined converter. In the second converter it is only necessary to add sufficient lime for the absorption of the phosphorus of the metal, and the blowing need not occupy more time than is necessary for the elimination of the phosphorus—about three minutes.

2261.



A. L. Holley pointed out, in a paper read before the American Society of Mechanics in 1880, that the maintenance of refractory linings in Bessemer steel converters in such a way as to promote regular and maximum production, has been the subject of more experimenting than any other feature of the Bessemer system, and it is still the least perfect and satisfactory feature, excepting, perhaps the casting of steel. Linings are not only eroded by the mechanical action of the charge, but they are chemically decomposed by its various slags. The silica linings usually employed have, indeed, been so improved that an average of say sixty charges in twenty-four hours can be got out of a pair of converters, and the shifting of interchangeable converter bottoms, containing the tuyeres, is so rapid that it does not delay production; but the repairing of the fixed lining just above the tuyeres, where both mechanical and chemical action are most severe, is frequently the cause of delay, and the operation rapidly performed between heats is tedious and costly. The accumulations of slag on other parts of the lining must also be quarried out, else the converter will become too small for the charge.

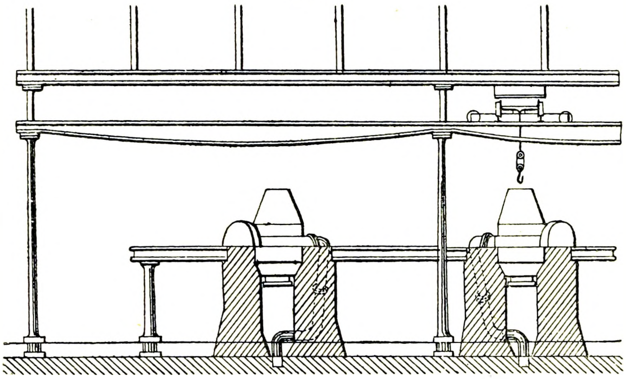
These are the conditions of maintaining silica linings; but the difficulties are increased, probably about threefold, when the linings are made of lime, for the basic process.

Basic bottoms and tuyeres stand ten to fifteen charges, nearly equalling acid bottoms, and they may be readily changed; but basic linings, near the tuyeres, and also in other parts where abrasion is severe, wear rapidly and must be frequently repaired by cooling the converter and inserting new bricks, or patching in some suitable manner. The converter is thus put out of use for at least twenty-four hours, a very serious delay to production. From a wide observation Holley states that a basic lining is rarely run above sixty charges without extensive repairs, and in some works repairs are made every time a bottom is set. With some irons there is also an accumulation of slag around the mouth of the converter; its removal sometimes also causes delay.

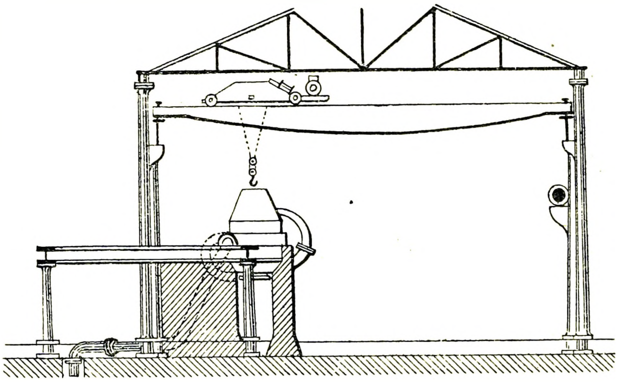
The output of a pair of converters in Europe averages about half that of a pair of converters of the same size in the United States, and is often less than half. The limited endurance of basic linings in Europe is therefore a less conspicuous defect.

There are two reasonable conditions of improvement; the one is to prolong the endurance of basic materials, so that their repairs can be made with little delay, while the converter is in position for use. There seems to be little or no progress or probability of immediate progress in this direction. The other is the rapid and complete removal of a worn lining and the replacement of a repaired one. A third system is to double or treble the entire converting plant. The only practicable way to replace a refractory lining, which cannot be handled by itself, is to replace the vessel which contains it. The worn portions of the lining may thus be repaired at leisure, in another part of the works, rather than in position for use, where repairs would retard output.

2262.



2263.



An obvious way to replace an entire converter lining is to replace the entire converter. This system is already under construction in Europe. The method is to lift the converter bodily out of its pillow-blocks, Figs. 2262, 2263, and convey it to the repair shed by means of an overhead traveller; then setting a repaired converter in place by the same means. Such a plant is doubtless cheaper than a duplicate plant, and its output should be materially greater than that of fixed converters. But the operation of changing an entire converter must be slow and tedious. When the arrangement is such that pillow-block caps are required, these must be loosened by unscrewing heavy nuts; then they must be made fast to the crane chain, lifted, traversed, and set down. The blast-pipe connection must be broken, and possibly some platforms must be removed. Then the traveller is placed exactly centrally over the converter, ponderous chains are made fast, the mass is raised high enough to clear surrounding parts, and drawn laterally to the repair shed; then the converter is placed centrally over its seat, and lowered and steadied, as it swings from a chain, into its pillow-blocks. The repaired converter is raised, traversed, and set in place by repeating all these operations; the blast connection is then made, and the pillow-block caps are lifted, traversed, steadied into place, and screwed down. If the converter is removed in sections, transferring each section and making the refractory joints will occupy much more time. The chimneys and the openings in the side of the building must be high enough to make passage not only for the traveller but for the converter when lifted out of its seat, and for the chains that sustain it. A traveller of the required power, height, and length is obviously a ponderous and costly structure, and to work with reasonable speed it must have independent steam power, since the hydraulic system of the works cannot well reach it.

The method of replacing the lining proposed by Holley is removing only the shell of the converter, lowering it out of the trunnion ring easily and rapidly, by means of a simple lift and car, and replacing a repaired shell by the same means. No pillow-block caps, blast connections, nor other surrounding parts are touched; a dozen cotters are knocked out, the shell is lowered and run straight back to the repair shed, the new shell is run in, lifted, and cottered on. The machinery and transference are on the general level, and not 40 feet or more up in the air. The car may be moved by a small reversing engine, or by a hydraulic capstan, by means of a wire rope and sheaves suitably arranged. The car runs against a stop, and the lift is perfectly vertical, so that the shell may be put in place by two rapid motions without the delay of adjustment.

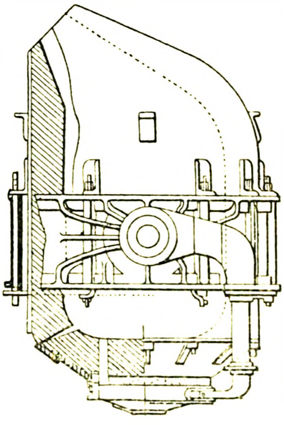
The lining may be heated before the shell is put in place, and bottoms and tuyeres separately removed, as at present, or they may be taken away with the shell, and repaired without removal from it. In the latter case, the shell must be placed in trunnions, in the repair shed, so that the bottom may be turned downward for repairs. But if the bottom is first removed, the shell need not be placed in trunnions in the repair shed; the shell will stand mouth downward on the car, a position most favourable for repairing both the mouth and the lining about the tuyeres, which are the two places chiefly needing repairs. This is doubtless the better plan, and it saves the cost of supplementary trunnion rings and turning gear. The converter may be hung so high above the general level that the bottom and tuyere box can be hauled out, with the shell, under the trunnion ring. In case the bottom is previously removed, the converter may be hung some 3 feet lower.

It has been remarked that in American works converter bottoms are changed so rapidly that one is always ready, even when tuyeres stand but eight or ten operations. Changing converter shells is much more rapid than changing bottoms. The several operations of removal and transportation are the same, but the converter lining must be trimmed out to receive the new bottom, and a refractory joint must be made. The new shell has merely to be cottered on.

The comparative cheapness of apparatus to change the shell, instead of the entire converter, is obvious. The two hydraulic lifts for removing the bottoms are made heavier, and there are several cars of simple construction; this is the entire extra apparatus. The increased cost of the converters is not important. In the other case the traveller, with its engine and the standards and turning gear in the repair shed, and the trunnion rings and pinions, the chief cost of the converters, for each spare shell approach in expense that of a duplicate plant complete.

To avoid damage to the lift under the converter, in case the charge should burn through and fall upon it, the lift table may be sunk several inches below the pit level, and covered with sand. Figs. 2264, 2265 are of Holley's plan for quickly changing the converter without removing the trunnion.

2264.



The trunnion ring, Figs. 2264 to 2265, is of cast iron, with an inch wrought-iron lining; if a steel casting, it will not require a lining. There is a 2-inch annular space between the trunnion ring and the converter shell, and the shell is prevented from shifting laterally by means of the wedges Fig. 2265. The car is raised by the lift to receive the shell; or the shell may be lowered by means of a fork on the lift passing through the car.

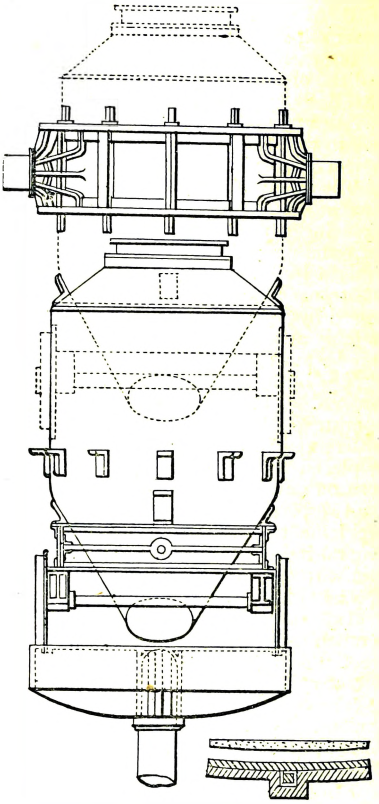
This construction of converters has led the way to a general improvement in the design of the plant. The shells and bottoms may be run out laterally into the converting house, but the space here is insufficient for convenient repairs, and the shells for one converter could not be well got to the other. In order that there may be one common place for repairs, and ample room both for spare shells and spare bottoms, they must be run out in rear of the converters. If blast furnace metal is brought directly to the converters, this rear space is not otherwise wanted, but if cupolas are placed there, as is usually the case, they must be so arranged that the shells can pass out under them.

But the cupolas, excepting the spiegel cupolas, may best be placed elsewhere; if there are blast furnaces the cupolas may be so arranged near them, as to utilize the same system of transportation, hoisting, blowing, and hot blast. There should be plenty of spare gas from good furnaces to heat cupola blast. These are very important considerations regarding both cost of plant and economy of working. And judging from the experience at many works, the disadvantages of hauling fluid iron some thousands of feet in a railway ladle, are less than those due to crowding the melting department and its stock yard and appurtenances close behind the converters.

Placing only the spiegel cupolas, instead of the entire melting department, close behind the converting house, leaves its rear comparatively open to free ventilation, thus cooling not only the space around the converters, but also the casting pit.

This arrangement provides ample room for the convenient removal of slag, which in the basic process is very voluminous; one long dumping car placed under both the converter and the ladle, catches it all; and as the bottom of the pit is on the general level, the slag is neither handled nor lifted, the car is simply hauled out by the yard locomotive and dumped.

2265.



Iron may be got to the converters in a ladle, by various means. It may be hauled on the general level, to one or more hoists, and run into short spouts or directly into the converter mouths, or it may be drawn up a gradual incline, or lifted by a hoist to an elevated railway near the converters, and thence tipped or tapped into them directly or through spouts.

The ladle may be run to the converter mouth by various means, so as to tip directly into it, but the application of power to the transportation is awkward and difficult, so that there is more or less delay. The ladle is drawn by a locomotive to short, steep spouts leading to the converters; there is no lateral nor hand movement, and hence no delay. A spout leads to each converter, chiefly for the purpose of leaving the space between the converters, where the common spout is usually placed, quite free for the spiegel ladle.

The spiegel cupolas and their appurtenances occupy so little room that they are placed, without interference with other apparatus, very near and above the converters. A railway ladle receives the spiegel from either cupola, and tips it directly into the converter quickly, and hence completely by a short run and without hoisting or lateral movement. It may be weighed in transit if desired. The wide platform between the converters is at other times free for bringing lime, scrap, or other materials to the converter mouths, and these materials are conveniently raised by the cupola hoist.

The floor of the converting house is raised a few feet, so that the pit-bottom may be on the general level, for the convenient removal of slag, as before explained. The ground outside of the converting house slopes gradually to the general level; this facilitates the removal of products, and also the drainage.

The plant for repairing shells consists of two turntables, some short railways, and a shed, also some platforms, and a lift for materials. If bottoms are to be removed with the shells, there must also be mounted trunnion rings and turning gear, also a crane, in the shed; but, as before explained, this seems unnecessary. Room is allowed for repairing four shells at a time, but the railways may be lengthened to accommodate more. The plant for repairing bottoms consists of short railways and turntables, a space for ramming bottoms under a shed, and the necessary ovens for drying them; also a crane which sets the bottoms directly on the oven cars. If tuyeres of ordinary size are used, fewer ovens are required; if the bottom is all one tuyere, rammed around rods, it must be burned for two or three days, so that more and hotter ovens are necessary. The repairing department may obviously be arranged in other ways, to suit special cases.

The average output of the American plant, having two 6-ton to 7-ton silica-lined converters in one pit, is 100,000 tons of ingots a year. It will doubtless appear that the plant under consideration should produce more with basic linings, because it has 10-ton converters, and means of keeping one of them in constant repair, so that the converting operations may follow one another without interruption.

The advantages of casting steel ingots in groups from below, that is, filling a number of moulds at the same time from one git or runner, are so great that many plans for casting in this way have been brought forward from time to time. The chief practical difficulty in casting in groups has been to find some entirely satisfactory mode of stoppering the ingots, when the moulds have been filled to the required height. In some cases they are stoppered in the ordinary way, by a thin iron plate covered with damp sand and wedged down; but to stopper in this way six or eight moulds, all full at the same time, before any of them begin to boil over, requires care and skill, and the plan also sacrifices two of the chief advantages of group casting, the cleanness and soundness of the top of the ingot, and the facility that is given, by filling up to a fixed stopper, for casting to exact weight.

Durfee suggests a method of making moulds for group casting closed at the top, with the exception of a small vent-hole; a plan that gives a very sound, clean ingot, but necessitates a different mould for each different weight to be cast, and renders it difficult to get out an ingot that may stick in the mould. Ireland uses a plain, heavy cast-iron stopper, dropped on the metal after the mould is filled, such as is used in casting ingots of tool steel from crucibles; a stopper of this kind, however, can only be used in parallel moulds, made in two parts, bolted or cottered together, and in these, even when planed all over, inside and at the joint, the ingots are apt to stick, and the moulds after having been in use for a short time open at the joints, causing fins.

A. L. Holley devised several modes of stoppering moulds, to be filled also from below; but they have not come into general use.

In Hackney's plan of stoppering, illustrated Figs. 2266 to 2273, the stopper used is a cast-iron block, about 2 in. thick, grooved round the edge, as in Figs. 2266, 2273, and of such a size as to drop freely into the top of the mould. A small vent-hole, about $\frac{3}{16}$ in. in diam., is drilled through it, and is made slightly conical that the metal may not stick in it. The stopper is fixed in the mould by two cast-iron wedges, as in the enlarged plan and section, Figs. 2269, 2273, and to avoid the necessity for having numerous wedges to suit different sizes of moulds, or heights in taper moulds, the sloped face of each wedge is made in three steps, so that each is in effect made up of three wedges of different thicknesses, side by side, and by using either of the three wedges forming one group, together with one or another of the three wedges forming the other group, the same extent of draw is obtained as by a single wedge of the same taper and nine times the length. To set the stopper in the mould the latter is dropped over a post of such a height that when the stopper is placed in the mould and on the top of the post it is exactly at the height required. A small shovelful of loam, such as is used in lining steel ladles, is then thrown in, and rammed into the joint by a rammer 2 or 3 in. broad, and about $\frac{1}{2}$ in. thick; the wedges are driven in to fix the stopper in its place, and the mould is then ready for casting. The loam, or mixed clay and sand, used should be only slightly damped, so that it will just cohere when pressed together in the hand. The post is adjusted to the required height by putting packing blocks or rings at its foot to raise the mould or by packing under its head, which for that purpose may be made loose and fixed by a set screw in the side.

In order to prevent the squeezing down of a fin of loam between the post and the inside of the mould, if the loam is rammed in too hard or if the rammer is thin, the head of the post should be a close fit in the mould at the height at which the stopper is fixed. For this purpose several heads are provided, or the top of the post may be made bevelled, Fig. 2272, and four small adjustable blocks placed on it when it is in position. These slide down the bevelled faces of the post into the corners of the mould, and close up the spaces through which loam might squeeze down. The only openings still left are those at *a a*, Fig. 2272, between the blocks, and in arranging the moulds for casting ingots, such as those for tyres, in which a perfectly smooth top is required, these are closed by laying over them small loose pieces of sheet iron before dropping the stopper in. Tyre ingots may be cast either in the form of solid cheeses, the more usual plan, or with a core, in order to save punching. Stoppers for both these plans of casting are shown in Figs. 2266, 2267.

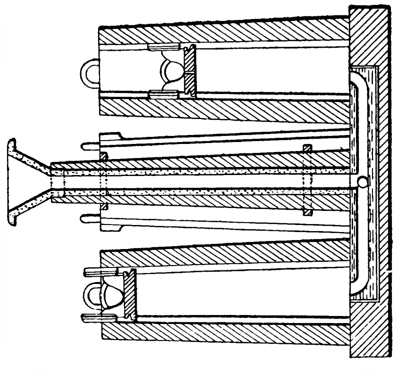
The moulds when arranged on the base plate are filled through a central git, with a branch leading into each mould. The central runner is made in two parts, locked together, or clamped, as shown in the illustration, rings driven over them; or by rings put on loosely, and fastened up by wedges, in the same way in which the halves of ordinary moulds for casting tool steel ingots are put together. The runners may be lined either with specially moulded bricks or pipes, or more cheaply with ordinary slightly damped ladle loam, or with mixed sand and clay, rimmed in round a wooden plug, which is then withdrawn. The funnel-shaped top of the runner is in a separate piece, put in after the lining is completed. The runners are dried by setting them over holes in a thick cast-iron plate, heated by a fire or a gas-flame; and, in order that the lining may dry readily, they should be perforated all over with $\frac{1}{2}$-in. holes, placed pretty closely together. Where there is plenty crane power, to handle the runners, they are most conveniently made of cast iron, heavy enough to stand firmly their own weight in casting; but where they have to be carried about by hand, they may be of light wrought iron. Both these forms of runner are shown in Figs. 2266, 2267. The light wrought-iron runners are bolted or cottered down, when in use; care being taken to cover the lugs and cotters with sand, before casting, that they may not become clogged with steel spillings.

The branch runners leading into the moulds are best made of moulded and burnt bricks, set in recesses in the bottom plate, and made firm by dry or nearly dry loam, rammed round them. The old bricks may be worked up, with a little fresh plastic clay, just sufficient to make the mass cohere, so that but little new material is required. Where the bricks are used in quantity, they may be made in a machine, in the form of plain pipe, like drain pipes, open at both ends; the hole in the top being cut by hand out of the unburned brick. The hole in the further end of the brick may either be filled up by a piece of clay, before it is burned, or closed with a little loam in setting it in place.

It is well known that under the conditions existing at most steel works considerable waste takes place, which could be avoided if the ingots were cast to the weight required. As a rule, the ingots are calculated at the rolling mill and ordered of the weight of the finished article to be produced, plus an allowance determined by practice, and it is the problem for the steel works to make them of this desired weight. The only means to attain this has up to the present day been the plan of calculation by volume, or in other words the calculation of the ingots of a given cross section, the height being marked with a chalk on the inside of the moulds, and this mark forming the only guide for the workman to go by.

With this method of casting ingots to a predetermined weight, no exactness can be expected, and to remedy this is the object of the arrangements, Figs. 2274 to 2281, for weighing steel ingots in the process of teeming, which have been designed by F. Moro, of the Kladno Steel Works, Austria.

In Figs. 2276 to 2279 the moulds stand as usual upon bottom plates, and these upon channel irons which are fastened to a base plate common to several moulds; in this manner there is sufficient room underneath to introduce a weighing apparatus. This consists of a lever, arranged as in Figs. 2274 to 2278, the apparatus being mounted on a suitable carriage running on rails, the weighing gear being also capable of being moved laterally by means of a rack guided in a frame, so that by turning the pinion which gears into the rack, the platform of the scale can be run out under the



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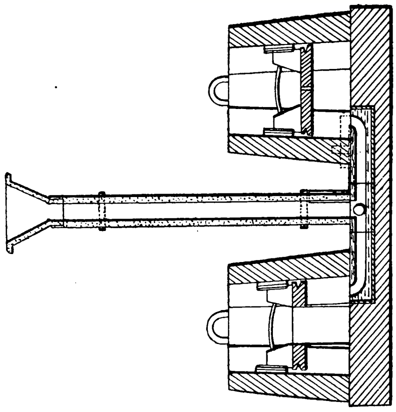

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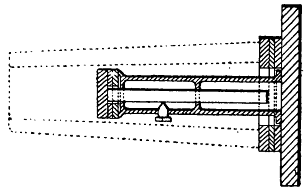

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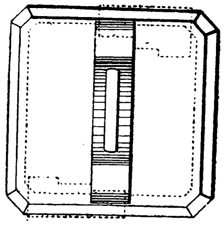

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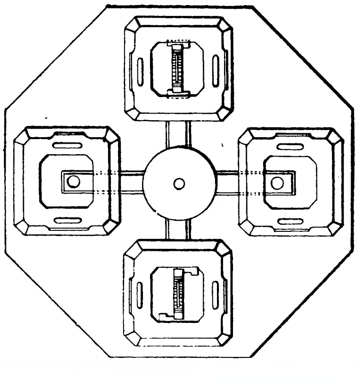

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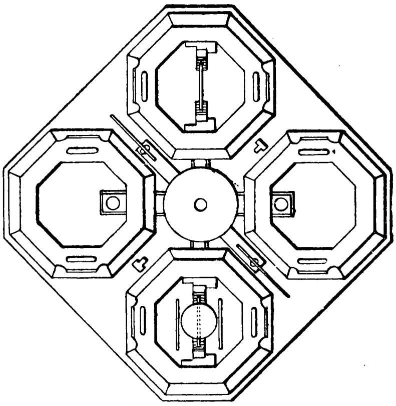

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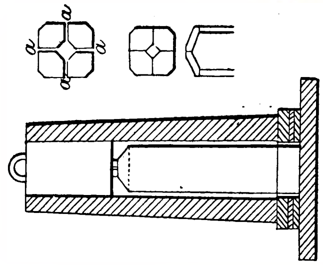

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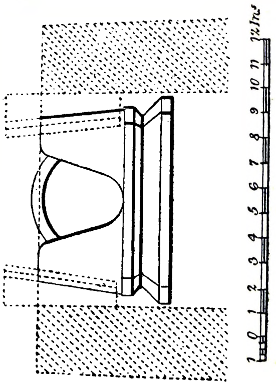
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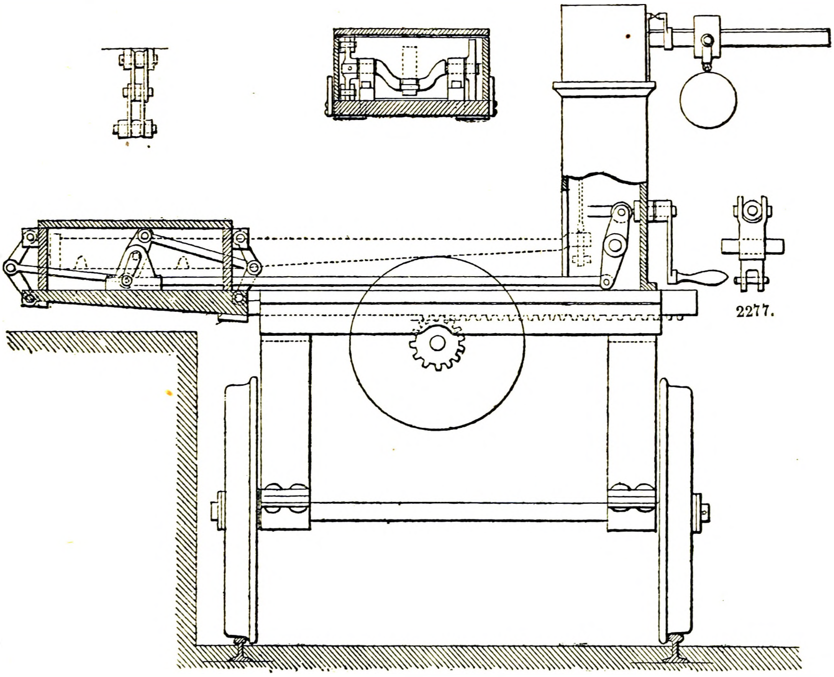
2273.

ingot mould to be weighed, the toggle joint then enabling the platform of the scale to be at once brought up against the under side of the ingot mould, so as to take the weight of the latter. Thus in this case instead of the body to be weighed being, as usual, placed upon the scale, the scale is raised underneath the body.

2274.

2275.

2276.



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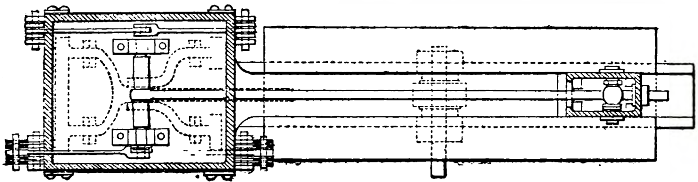

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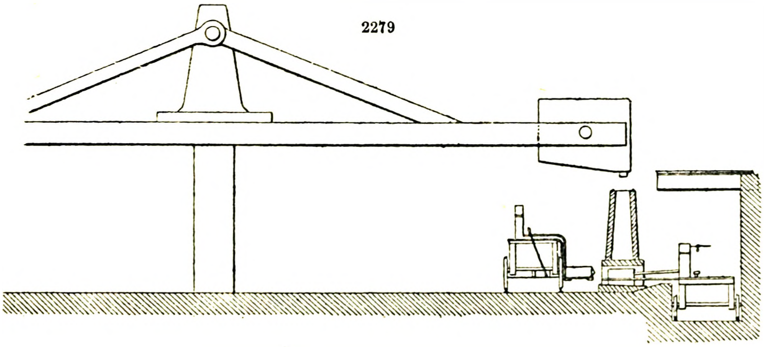
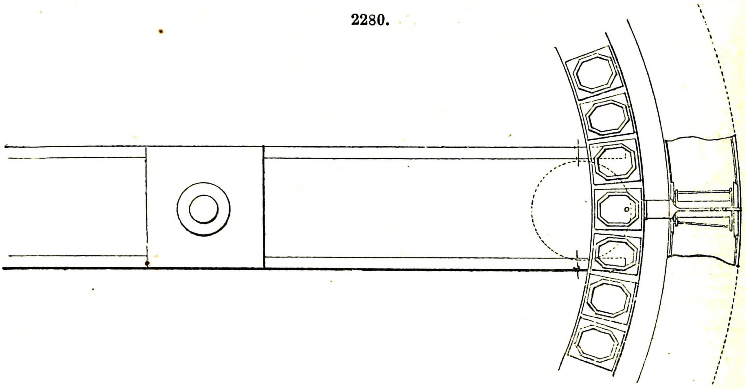


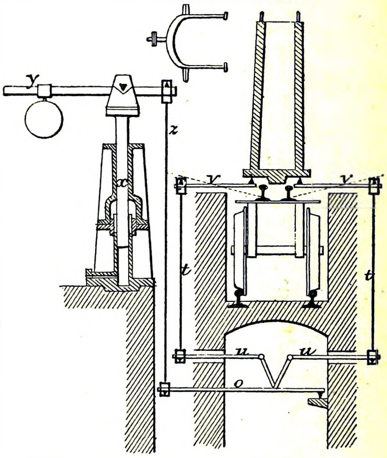
After the required weight of metal has been run into the mould, the operator that is pouring can immediately bring the table over the next mould, without regarding the weighing apparatus, as before he has cast half the next ingot the apparatus will have been lowered, withdrawn, and brought under the mould now to be filled. In this way the teeming of a charge is not delayed. The apparatus is closed perfectly, and so an accidental spattering round of the metal cannot injure it in any way, and for the same reason the attendant is protected by a shield. Should any serious danger threaten the apparatus, the latter can be withdrawn and removed immediately. The apparatus, Figs. 2274 to 2278, is especially arranged for moving on a line of rails sunk below the level of the pit floor and outside the line of ingots, as in Figs. 2279, 2280. Fig. 2279, however, also shows how a slightly modified weighing machine can be arranged on rails inside the line of ingots and on the level of the pit floor, if desired. The apparatus should, if possible, be placed between the moulds and the border wall of the pit, which wall for this reason must be put back about 24 in.

2280.



In another arrangement a scale is used which is stationary, and which takes hold of the mould bottom plate from two sides. This is like weighing on two scales united into one. The stationary scale is used in this case, as the pit is so arranged that the moulds are run upon trucks, and the ladle remains stationary. The arrangement is shown in Fig. 2281, from which it will be seen that on the platform of the mould trucks two rails are rigidly fastened, these serving for the mould plates to rest upon. In this manner room is made for the scale levers, which when the scale is put out of action are in the position indicated by dotted lines, thus letting the bottom plates pass over them as the mould trucks are moved along. The train of mould trucks is so arranged that when a mould to be weighed arrives above the scale levers *v*, an exact adjustment of the mould is not necessary if the bearing edges are placed at sufficient distances from each other. The truck being in place a cock is turned, and hydraulic pressure is brought underneath the plunger *x*, which raises the main centre, and exerts a pull by means of the lever *y*, fixed at this time, on the connecting rod *z*. This raises the one-armed lever *o*, and by it the bottom plate is, through the levers *u* and *v*, and links *t*, raised and brought in balance so that the weighing can proceed.

2281.



Before casting, it is necessary to know the weight of the empty mould. This can be ascertained in different ways, either by making the moulds of one kind of the same weight, by correcting the differences they originally show by shrinking on iron bands of different weight, or by marking the weight of each single mould in plain figures upon it, and from time to time weighing the moulds over again to observe any possible alterations in their weight. As the sliding weight on the scale beam or lever is put to mark the weight of the ingot to be cast, the beam is before and while pouring in a downward position, towards the end of the pouring, it slowly begins to rise until the play of the scale indicates that the block has been cast of the desired weight.

STONE-WORKING MACHINERY.

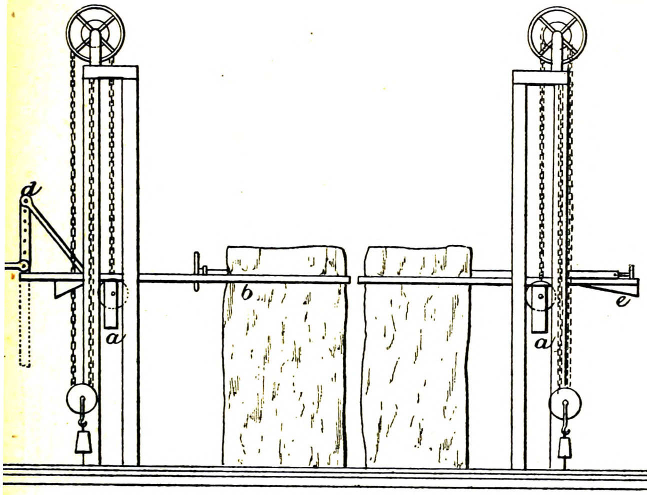
Machinery is at present employed for sawing, planing, and moulding stone, but except for contract work, where large blocks and slabs are required of regular dimensions, stone-machinery is still restricted to the special uses above mentioned.

It has been frequently attempted to use the impure black diamonds for cutting stone, and although they are of such endurance as to stand constant use, yet there seems still to be considerable difficulty, not in the construction of the machines, but in the method of holding the stones, which render them somewhat expensive for ordinary purposes. A diamond saw consists of a common saw, either circular or reciprocating, its teeth pointed with diamonds, which are imbedded or clamped in the steel, so as to present a surface so much wider than the saw blade as to permit the latter to pass freely through the kerf. The slit or kerf, however, is generally wider than the thickness of the diamond-pointed edge, which is the result of granular abrasion beyond the teeth. It must not be inferred that the diamonds employed are larger in diameter than the thickness of the saw plates. By staggering them, that is fixing them alternately first on one side and then on the other, corresponding to the setting of a saw for wood, the carbons can be comparatively small and yet cut their way.

Figs. 2282 to 2284 relate to a simple and effective stone-sawing machine.

The machine consists principally of four uprights, each made of two semi-balks placed sufficient distance apart to admit of the vertical motion of the cross bearers *a*, carrying friction rollers *c*, upon which the saw frame reciprocates. The latter consists of two longitudinal pieces of angle iron connected together at the ends by two pieces of flat iron, Fig. 2283, which form the means of holding the saws at different or equal distances apart. The saw frame is thus very light, and requires little power to move it. The bearers *a* are suspended from chains running over short barrels mounted, at the top of the uprights, on shafts carrying also grooved pulleys, over which run chains from balance weights, by means of which the whole or any portion of the weight of the saw frame and saws may be brought to bear upon the cut.

2282.



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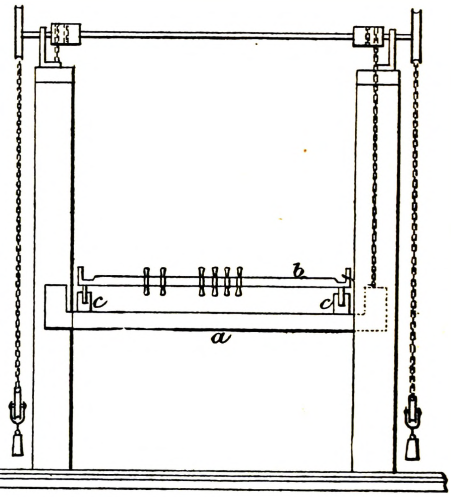
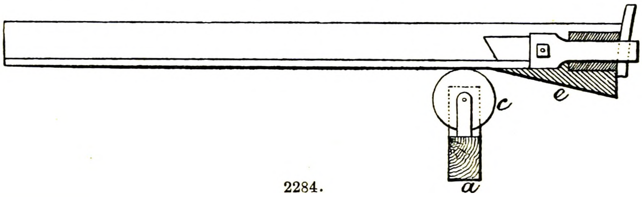
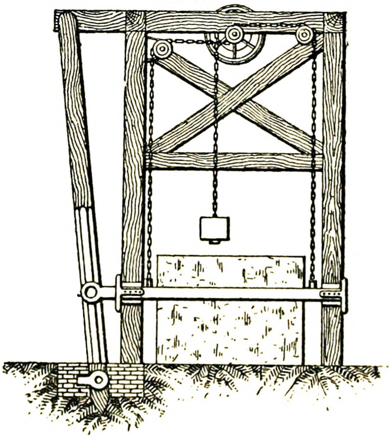




2284.

At the under side of each end of the saw frame is fixed a wedge-shaped piece of wood covered with iron, forming an inclined plane *e*, Fig. 2284, which at each end of the stroke runs up on the friction roller *c*, thus lifting the saws and allowing of the supply of new sand to the cutting portions just as they begin a new stroke. The vibrating arm *f* from the engine, by which the saw frame is moved, is attached to a flat bar *d* with several holes in it, into which the pin connecting the vibrating arm *g* therewith, may be shifted as the saws descend into the block of stone. This vertical bar is firmly stayed, and in such a manner that it may be readily fixed in the position indicated by the dotted lines, so as to keep the end of the arm *f* at such a level, that it may not tend to lift the saw frame when it is on the top of a large block of stone, nor throw any pressure in an oblique direction upon it when at the bottom of a block. The end of *f* is attached to a crank pin, the shaft carrying which is of a fixed level, so that the angle which would be assumed by the arm, without some such arrangement as that described, would be occasionally sufficient to greatly decrease or increase the pressure on that end of the saws, when at the top or bottom of a block respectively.

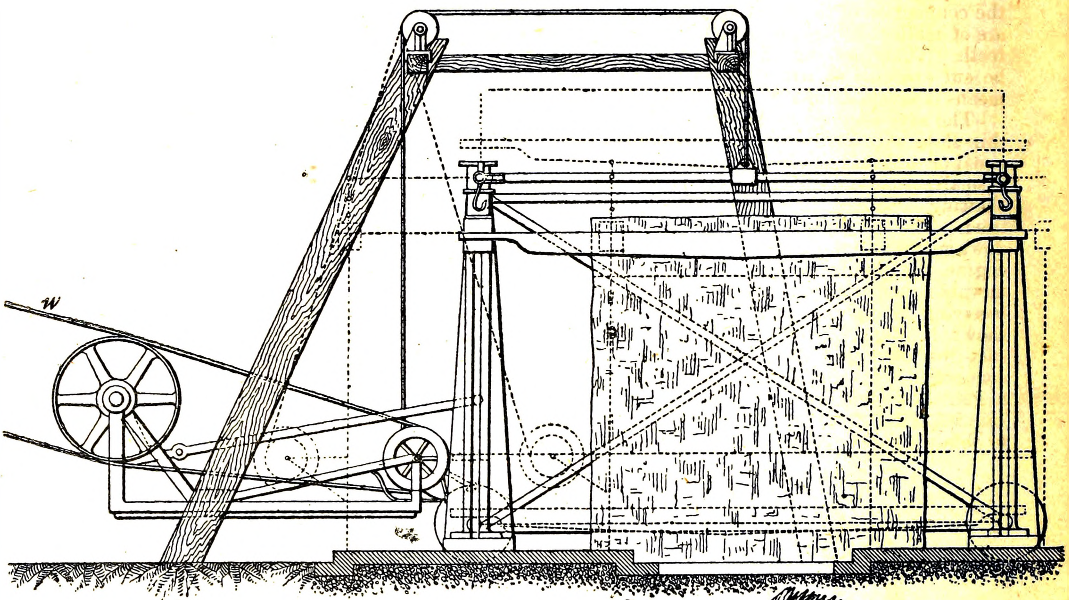
2285.

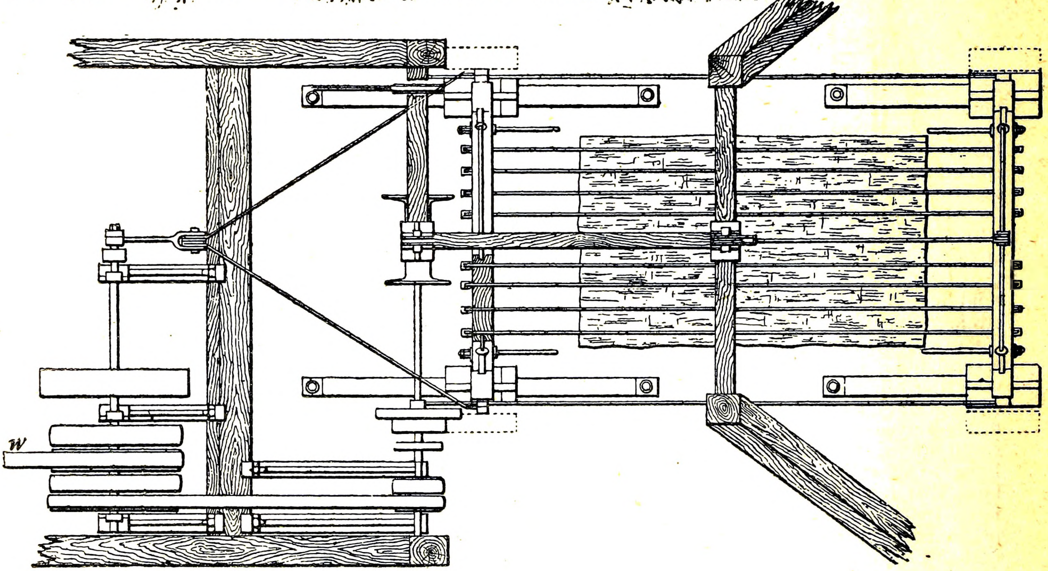


With an engine of about 2½ horse-power, a rough machine of this description will cut 100 sup. ft. of hard Portland stone in 10 hours. About seventy strokes a minute is found to be the best speed, and 16 in. to be the best length of stroke, the sand being worn out after having travelled that distance. Feeding in the sand by hand-supplied water is adopted, as the saws most needing it may be given a larger quantity.

Figs. 2285 to 2287 show the machinery in use for sawing stone in large works in London. In Fig. 2285 four timbers of about 9 in. square and about 12 ft. high are driven into the ground, and are united at the top by cross timbers and by outside diagonal timber bracings, forming a compact and solid stand. Between the stand, and fixed to the top cross timber, is vertically suspended a timber called the swinging boom. Between the stand moves the saw frame, which is suspended at its four corners to the stand by means of chains. On the top are the necessary pulleys and drums. The sawing frame consists of two longitudinal cast-iron arms about 12 ft. long and 4 in. deep, which are provided at their ends with longitudinal openings to receive two wrought-iron bars, which are

2286.



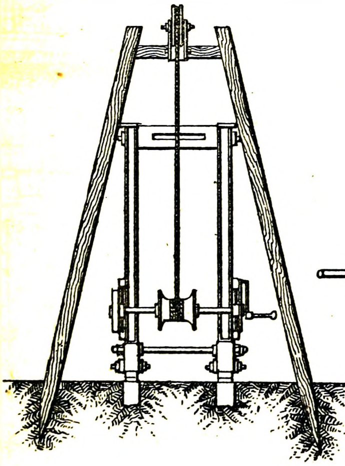


2287.

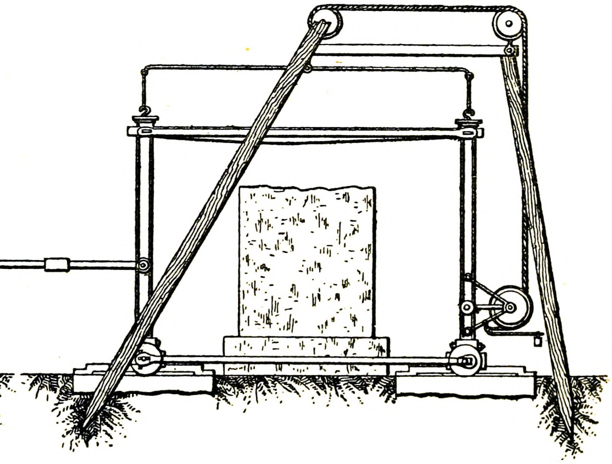
about 6 ft. in length, 2½ in. in breadth, and 2 in. in thickness, between which the saws are keyed. One end of the saw frame on each side is provided with a small arm bearing a slide piece, which serves as its guide and connection by sliding in the vertical slotting which is fixed to the swinging boom, and comes into action by the down and upward motion of the saw frame. The suspension of the sawing frame is carried out as follows;—The chains attached to the end of the frame facing the swinging boom are coiled over and fixed to the drum which is placed on the front pillars, while another chain runs from the same point of the frame over the large pulley fixed to the shaft of the back drum, which is placed on the top of each pillar carrying a counterbalance weight. The chains or ropes of the free back end of the saw frame are coiled over and fixed to the back drum, while again another chain fixed at the same point of the frame having also a counterbalance weight attached to it, is running over the large pulley placed on the shaft of the front drum. On each side of the stand are placed winches, from which endless chains are running over the large pulleys for winding up or lowering the frame with its saws. In a similar arrangement, but less complicated, the suspension chains, Fig. 2285, run from the two corresponding points of each side of the frame to a central drum on which they are fixed. Over a large pulley fixed on the same centre shaft, but placed outside the stand, is suspended a chain with a weight to counterbalance the saw frame, while a second endless chain running over the outer ring of the same pulley sets it in motion, thus lifting or lowering the frame. The forward and backward motion of the saw frame, which is connected through slide pieces to the swinging boom, is effected through the connection of the latter with a steam engine or to a main shaft driven by an engine. The saws are of malleable hammered iron, about 8 ft. long and 5 in. wide by $\frac{1}{8}$ in. thick, plain-faced, without teeth. There are from five to ten saws, and sometimes even more, in one frame. The blocks to be cut are either carried to the machine by trucks moving on rails, or are placed in position by means of steam cranes.

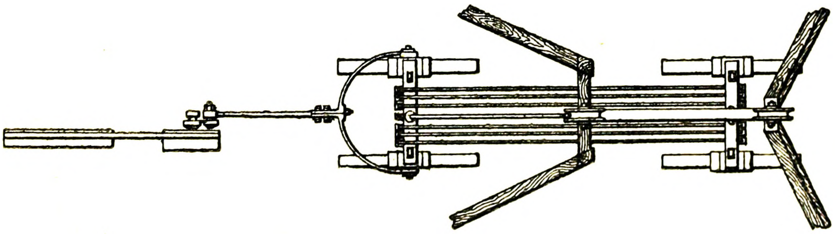
The saw designed by H. Conradi is for the purpose of sawing blocks of costly marble into very thin slabs with as little waste as possible. The slabs cut out of the same stone can be either of equal or different thickness, but have as nearly as possible a parallel cut. The machine occupies a small space and can be easily removed, and be driven either directly by a steam engine or from shafting. Conradi has reversed the principle of the marble and stone sawing frames generally used. The principle of the ordinary saw system consists mainly in a to-and-fro and an up-and-down motion of the saws, carried on by means of a freely-suspended movable boom attached to the engine, the saw frame being moved in a fixed frame. Conradi transforms the fixed stand into a movable one, carrying the saw frame with it in its forward and backward motion, the latter receiving its up-and-down motion by means of a suspension arrangement. The arrangement is shown in Fig. 2286 in sectional side elevation. In the first design the frame consisted of four cast-iron columns bolted firmly together at the top and bottom, the front pair being directly connected to the engine by means of connecting rods, while the other pair was guided by means of a guide bar bearing on a chair placed behind it. They were provided with vertical grooves running inside from top to bottom for the reception of the saw bearers. For greater stability, and to obtain the cuts in the marble as straight and as parallel as possible, the columns run on square slides instead of rails, thus avoiding as much as possible the influence of vibration to which the frame may be exposed through irregularities in the engine by the saws encountering layers of different hardness in the material to be cut.

2288.



2289.





2290.

The saw frame consists of two cast-iron transverse beams provided with longitudinal openings for the reception of the saws, which are keyed on one of the booms moving up and down in the grooves of the front columns, the other moving in those of the back columns, which are bolted firmly together, Fig. 2287. The saw bearers are fixed to a longitudinal beam running from centre to centre of the saw bearers by means of vertical connecting rods, the bearers being suspended by means of ropes, or chains, which, running over guide pulleys, are coiled round the drum of an ordinary hoisting crab, provided with a brake fixed on the drum shaft. The brake is worked by a counterbalance weight on a lever, thus regulating the speed of the drum, and with it, through the winding up or unwinding of the rope, the up-and-down motion of the saw bearers. At intervals of about ten minutes the attendant distributes the sand and water used for sawing, and also effects the lowering of the saw bearers and places the frame in equilibrium by altering the position of the counterbalance weight on its lever. The pulleys for the ropes of the beam suspension arrangement are carried by chairs or plummer blocks fastened to the ceilings, the driving or loose pulleys being placed on the shafts. The saw frame works with five saws.

The practical difficulties found in setting the machine to work were the tightening of the saws and preventing the wear of the slide pieces from the water and sand falling on them. The first difficulty has been overcome by means of strong stays, which keep the columns and saw bearers at the required distances. The second difficulty was met by fixing a cover to the foot of the column, and thus preventing the water and sand spreading around.

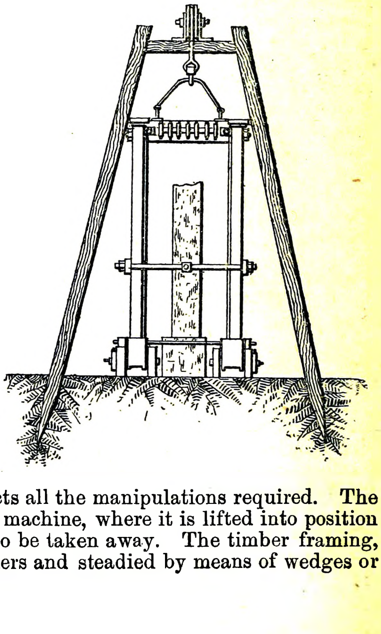
As regards the stays of the saw bearers, they are usually straight wrought-irons bars of about 1 in. in diameter. They are also made curved in order to allow any size of stone to be brought under the machine, and to avoid making the framework of too great width. In some instances Conradi found that the sawing could be effected without fixing the stays to the saw bearers, if the nature of the stone did not require the saws to be very strongly tightened up.

With regard to the work done by the machine, the cutting being obtained through the pressure exercised by the saw on the stone, the grit used thus entering into the pores of the soft iron produces a rough cutting surface. The resistance of friction to be overcome along the rubbing surfaces, the travel of the saws, and the pressure, are therefore the data to be considered. It is to be observed that some saws working with a swinging motion cut only four-fifths of their length, the saws being shaped accordingly, while others cut with their entire length. The pressure of the saws on the stone varies according to the softness or hardness of the latter, and it is not much greater in a steam than in a hand saw, as the greater pressure does not give a truly clean cut, but will rather tear pieces off the stone, or, if the material is too hard, will heat the saw. Therefore the saw is balanced until its pressure on the stone is equal to that exercised by a man, which Conradi assumes to be about 20 lb.

Assuming the engine to be making 120 revolutions a minute, and the travel of the saw to be about 5 ft., we have; speed of saw = 120 × 5 ft. × 2 = 1200 ft. The coefficient of friction of stone on stone being = 0·71 in cases of repose, that of motion being = coefficient of repose × 0·7, we obtain therefore: work of cutting = 1200 ft. × 20 lb. × 0·71 × 0·7 = 11,928 foot-pounds a minute. Assuming further, in round figures, the weight of the cast-iron framework, with its accessories to be = ½ ton, it follows that the pressure on the slides will, with 1 ft. 6 in. stroke of saw, become 120 rev. × 2 × 1·5 ft. = 360 ft. of travel, thus the work produced = 360 ft. × 1120 lb. × 0·18 × 0·7 = 50,803·20 foot-pounds, giving, as the work of cutting = 11,928 foot-pounds, work of frame motion = 50,803·20 foot-pounds, a total of 62,731 foot-pounds a minute, or $\frac{62731}{33000} = 1\cdot90$ H.P. Taking the frame composed of five saws, the work of cutting will be as above; 1200 ft. × 20 lb. × 5 ft. × 0·71 × 0·7 = 59,640 foot-pounds, work of frame motion as before = 50,803·20 foot-pounds, making a total of 110,443·20 foot-pounds, or 3·34 H.P. a frame.

This result is somewhat higher as shown by practical results, the coefficient of friction and the pressure on the saws apparently becoming reduced during motion, and therefore losing some of their direct influence and amount by working several saws together. With one frame a stone from 6 ft. to 8 ft. in length will be cut, according to its softness, to a depth of from 2 ft. to 2 ft. 6 in. a day of nine hours.

2291.



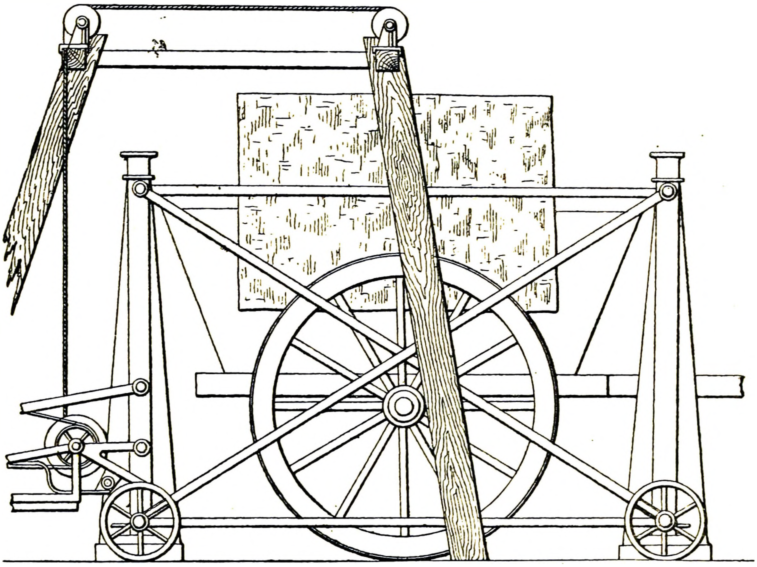
A further improvement made by Conradi consists in fixing the winding drum directly on the apparatus, and in setting the machine on rollers for the purpose of cutting ordinary stones, Figs. 2288 to 2291. This led Conradi to transform it into a portable machine, and to enable it by means of timber framing, bearing the suspension arrangement of the saw frame, to be used on open ground, and to be carried from one building site to the other, thus enabling the builder or contractor to have the stones cut directly on the spot, instead of being sent to the stone sawing yard. The economy in time and labour thus obtainable is worthy of consideration. It is specially applicable for small buildings, where the contractor, after having the stones cut in one place, could send the machine to work at another place.

The requirement of this kind of work is fully met in this machine, the practical value of which is increased by providing it with a lifting arrangement, and in using the drum for the up-and-down motion of the saw frame for lifting and lowering the stone. The machine thus effects all the manipulations required. The stone coming from the quarry is carted directly under the machine, where it is lifted into position ready to be cut, and when finished is replaced in the cart to be taken away. The timber framing, shown as driven into the ground, can also be placed on rollers and steadied by means of wedges or similar arrangements. The cast-iron framework, Fig. 2286, is placed on ordinary road rollers travelling over ground laid with gravel. The lifting apparatus is fixed to a bracket provided with a shaft, and which is either fixed to the boiler of the engine in a temporary or permanent manner. In the former case several iron bands carrying the brackets are bolted to the boiler and secured by set screws. A driving belt runs from the engine pulley to a pulley on the shaft of the lifting apparatus, where from another pulley another driving belt is carried to the driving pulley, which is keyed to the drum shaft of the saw frame.

During the operation of lifting or lowering the stone, the saw frame with its suspension arrangement is taken off, but the pulleys guiding the rope or chain, being fixed to the timber frame, remain.

The dotted lines in Fig. 2286 show the different positions of the machine during its travel. The operation of lifting the stone from the cart and placing it under the saw frame is seen at Fig. 2292, the stand being there represented for the purpose of cutting stones on road rollers, showing that there is no difficulty in moving the sawing apparatus placed on slides or on rollers, the machine being arranged so as to allow the one to be replaced through the other according to the kind of work to be executed. After the stone has been placed, the lifting apparatus is thrown out of gear by uncoupling the whole arrangement or by shifting the driving belt on a loose pulley, Fig. 2287. The shaft of the lifting arrangement is provided, Fig. 2287, with a fly-wheel, but as the operation of lifting and lowering the stone takes only a very short time, these operations could be effected without it and with a gain in economy. The saw frame, consisting of its bearers and saws, Figs. 2287 and 2293, is then put in position by attaching the ropes, which have again become free, to the suspension arrangement. The machine is set to work until the cutting is finished, when the suspension arrangement and the saw frame are again taken away and the lifting apparatus thrown into gear to lift the stone on to the cart to be carried away.

2292.



2293.

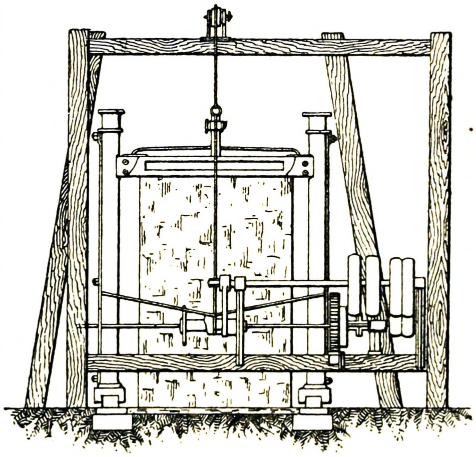
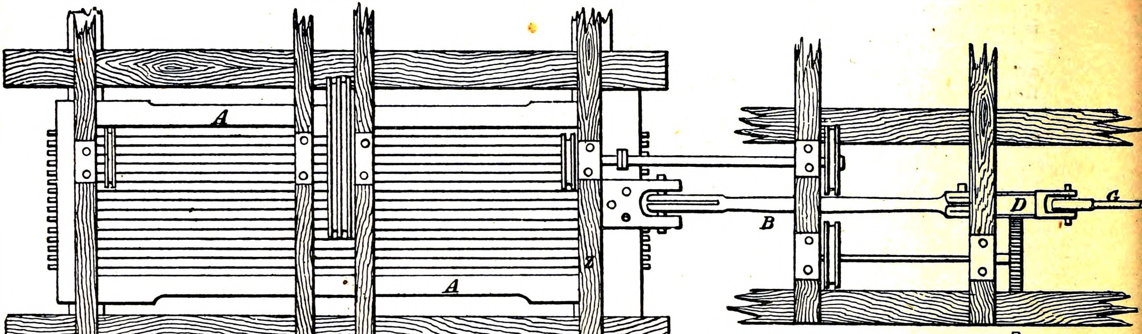
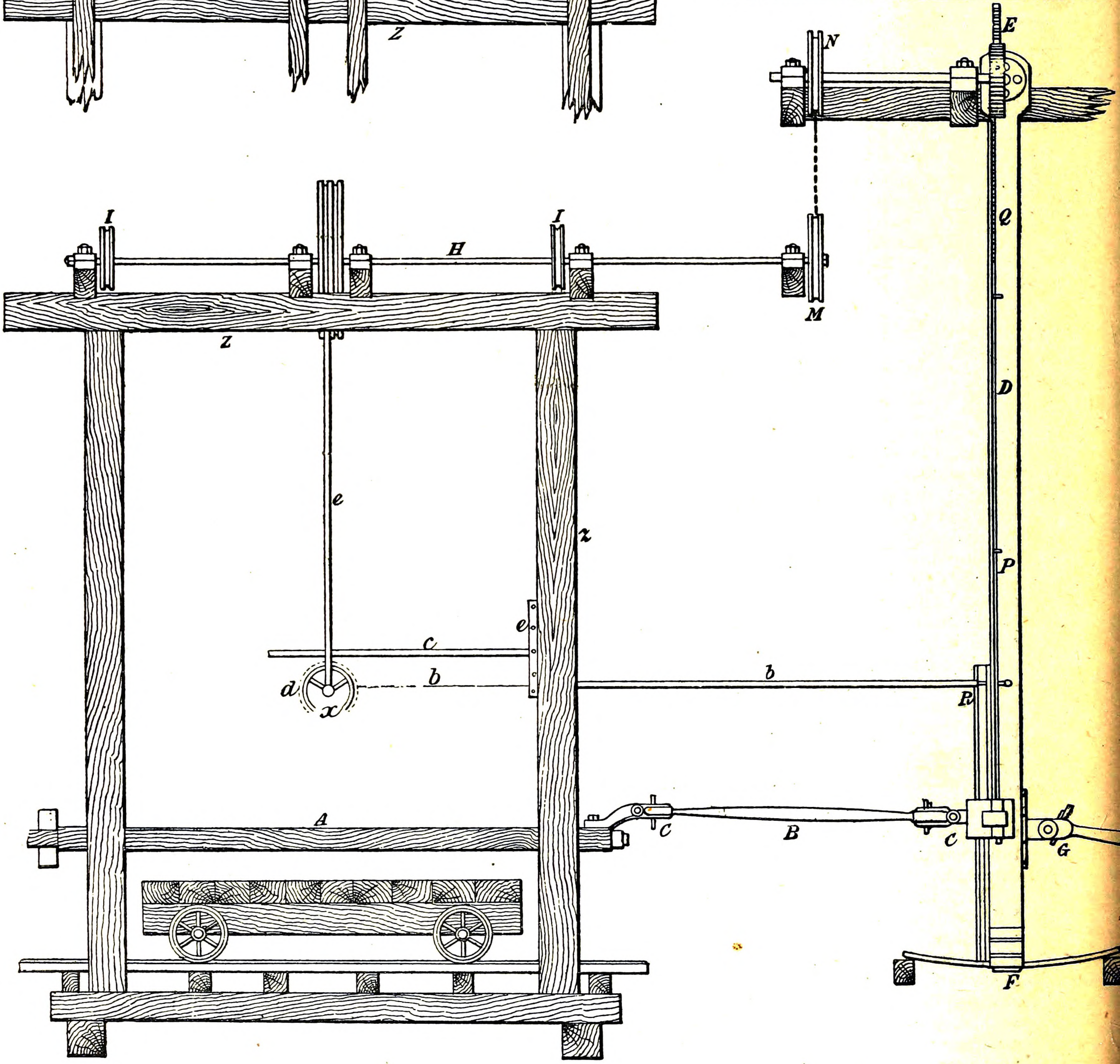


Fig. 2294 is a ground plan; Fig. 2295 a longitudinal elevation; Fig. 2296 an end elevation; Fig. 2297, 2299 details of driving disc; Fig. 2298, top view, showing direction of screw and manner of working of a plant for sawing stone designed by T. Glaister, and used with success in the English colonies. A is a saw frame of the ordinary description; B a connecting rod with two ends C C; D a pendulum for driving the saw frames suspended at E, working at the lower end in a guide F, by friction rollers, and driven by a connecting rod G, attached to the motor; H is an axle for suspending the saw frames; I I, pulleys from which the saw frames are suspended by the hangers J; there are two central pulleys L, which may be placed in any position on the axle, the one being for balancing the frames, the other for lifting them from or lowering them into their cuts; M is the point to which the axle H is extended from the main framing Z, it is connected by an endless chain to the upper pulley N; these two pulleys should be the same diameter as I I; O is a cog wheel placed on the same axle as N, and of equal size, it works the

2294.

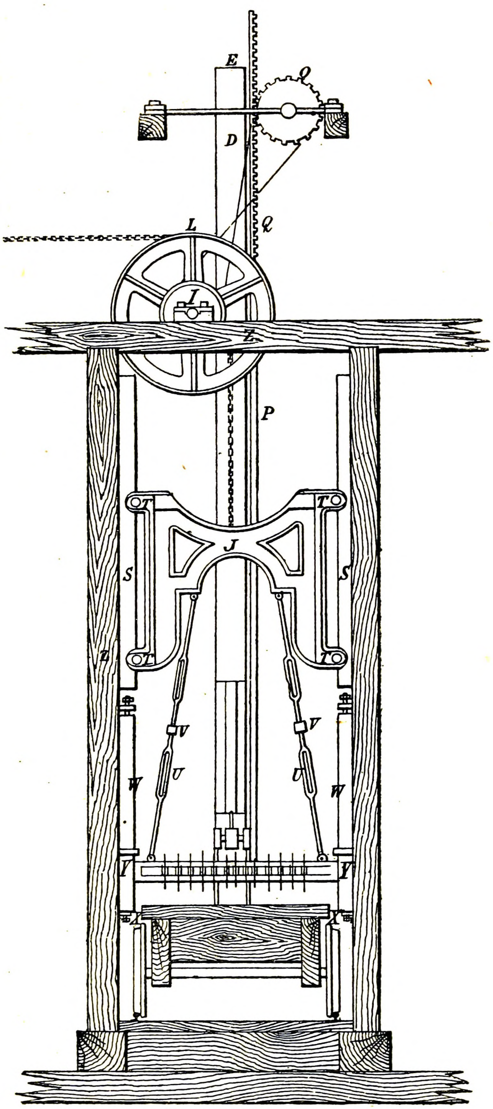




2295.

connecting rod suspender P by the rack on the upper end Q, which being secured on the connecting rod B, and working in guides up the pendulum, keeps the connecting rod on the same level as the frame, and travels up and down guides R at the same speed; the pulleys I I and L taking the rise and fall of the saw frames at each stroke, but conveying the motion no further than their own axle; one of the central pulleys L has a loose clutch, and may be keyed to allow the axle to work freely to the left of the frame, a considerable distance at each stroke, and communicates no motion to the pulley N or cog wheel O, except as the cut progresses; the hangers J work on

2296.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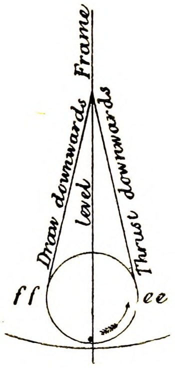
2300.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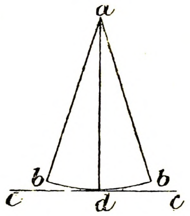

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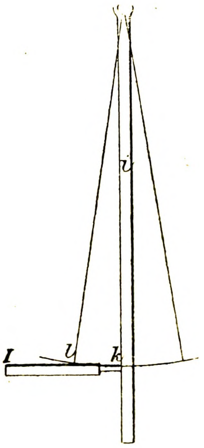

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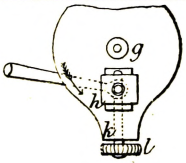

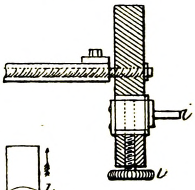

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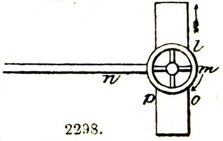


2298.

vertical guides S S, with the friction rollers T T; these are adjusted, when worn, with set pins; the suspending rods U U can also be altered at V to regulate the sweep. On the side of a pulley, on the main axle H, a small break is placed to regulate the lift of the frame at each stroke, it is controlled by the weight attached; W W are friction rollers secured by brackets at each end, they can be adjusted, when worn, by set pins Y Y.

Figs. 2297 to 2299 represent the method of shortening or lengthening the stroke when the machine is in full motion, so as to give the saw frame the same swing when lifted to its utmost height, as at the lower part of the cut. The face of the disc, Fig. 2297, is strengthened at its upper side, and revolves on an axle *g*; *n* is the slot in which a block is fitted with overlapping flanges, holding a driven pin *i*, and sliding up and down in the slot; *k*, a strong rod which passes through the block secured above and below, but allowing it to revolve. This rod is screwed at its upper end, passing through the rim of the disc, and terminates with a small wheel *l*. By applying friction at *m*, Fig. 2298, this wheel will, at each revolution of the disc, revolve in the direction of the arrow *o*, pressing down the block, and shortening the stroke; applying friction to the side *n*, the wheel will take the opposite direction and lengthen the stroke.

The sand feeder is a hollow tube extending across the cuts, with perforations for the discharge of sand and water; it is driven by a connecting rod *b*, attached to the pendulum; this can be lifted or lowered to suit the material to be cut, by a rack above, and corresponding rack *c* below; inside the tube is an agitator, kept in constant motion by a segment wheel *d*, and it is supplied with sand and water by a pipe at the line of *e* from the hopper above. The débris and water from the cuts fall into a cistern, they are then raised by elevators to a shaking table, where the silt is separated from the grit, the latter passing to an agitating cistern above, and thence to the feed pipe.

Figs. 2300 to 2302 illustrate graphically the difference in the various modes of suspending stone saw frames.

In self-feeders by machinery without balance weights, Fig. 2301, *a* is the fixed point of suspension, *b b* the extreme length of stroke, and the line *c c* the material to be operated upon; when the frame is raised by the backward or forward motion to the extreme point *b*, it is lifted considerably above the material, and can only touch it at the point *d*, the remainder of the stroke being altogether lost; and immediately upon coming into contact with the bottom of the cut, having no elasticity, it crushes the sand at once instead of by gradually rolling it on the surface of the cut, the cutters afterwards running with little pressure on the stone without sand with the trolly motion, in which the frames run with sweeps, on rollers attached to hangers, but having suspended weights, and driven by a disc, wiper, or crank motion.

Fig. 2300; the frame is shown level with the driving axle, which is the best position for cutting; yet on the disc revolving in the direction of the arrow, at points *e e* and *f f*, the thrust and draw is downwards, acting against the balance weight by giving additional weight to the frame, while near the two centres no pressure takes place; this pressure is greatly augmented when much above or below the level of the axle, in which case, acting alternately, the balance of the frame is destroyed, so as to reduce to a great extent the work.

The pendulum motion, Fig. 2392, which has less defects than the other two, but is still deficient. I is the frame, *i* the pendulum, *k* the connecting rod, and *l* the length of stroke. When set in motion the circle shown is described, and on the frame lifting to its balance weight, by a thrust or a draw of at least six tons, in ordinary working, the connecting rod slides up and down the pendulum with considerable friction, materially augmenting the power required; and at the same time, when lifting, the frame retards it by friction, partially overcoming the balance weight, and, when the frame falls to the stroke, partially suspending it, so the weight required to cut effectually can only be attained at one point of the stroke; and, at the same time, the friction of the connecting rod with the pendulum causes it to slip by jerks, preventing a higher speed being attained than from forty to forty-five strokes a minute, while a much higher speed is desirable.

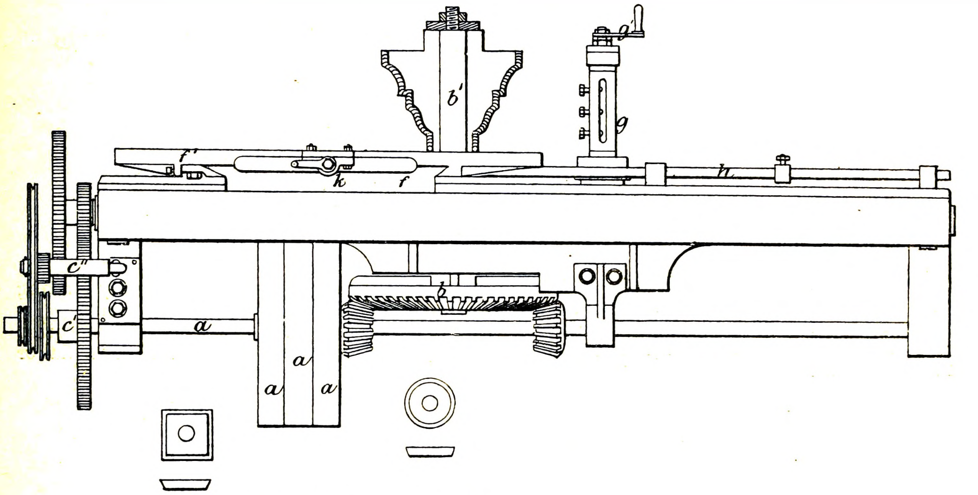
In Fig. 2295 the connecting rod suspender is arranged on the front side of the pendulum, to convey a clearer idea of its operation, but it may be placed on the other side, which will prevent the crossing of the band or endless chain. The axles of the pulley N and wheel O can be lengthened to the main framing Z, when the pulley M will work by the side of the pulley I.

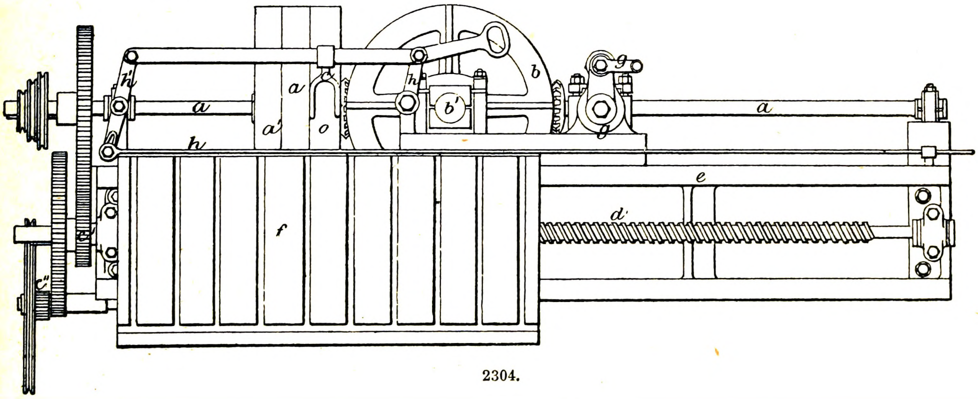
Fig. 2303 is a side elevation, and Fig. 2304 a plan of Cooke and Hunter's machine for facing or moulding the edge of a stone. *a* is the driving shaft, *a' o* two loose pulleys. The pulley *o* has fixed to it a bevel pinion, and the shaft *a* has upon it another pinion, both gearing into one bevel wheel *b*. The driving strap, guided by a fork *c* while running on *a'* drives the shaft *a* and the bevel wheel *b* in one direction; when it is on *o* it drives the wheel to which it is attached, and the shaft *a* in the opposite direction. *b'* is a shaft to which the wheel *b* is fixed. This shaft carries the rotating cutting barrel, or plates. The shaft *a*, by means of gearing *c'*, drives a screw *d*, or when *c'* is brought into gear with *c''* the screw is driven at a different speed by a band from the shaft *a*. *e* is the bed of the machine, on which is mounted a sliding table *f*, which is moved to and fro by the screw *d* like the table of a lathe. *f'* is a transverse slide, on which is placed the stone to be operated on. *g* is a standard which is mounted in bearings, so that it can be turned round or raised or lowered by means of a screw and handle *g'*. This handle is slotted to receive a scraping tool, which consists of a flat plate of steel shaped to the profile of the moulding, and which is secured in the slot by set screws. The rotation of the standard *g* is limited by suitable stops, so as to bring the scraping tool against the stone, or to turn it clear from it. *h* is a self-acting reversing bar connected to the fork *c* by levers *h'*, and working like that of a planing machine.

The stone to be operated on is secured upon the slide, the gearing for working the screw *d* being so set as to give the table *f* a slow forward travel. The cutters on the shaft *b'* rotating while the stone advances, the edge of the stone is cut to the form determined by the profile of the cutters. The slide is drawn back by means of a hand-screw *k*, so as to bring the edge of the stone clear of the rotating cutters. The scraping tool is brought around into position by turning the standard *g* so that its edge is presented to the stone, and the gearing of the screw *d* is altered to give the table a quick travel. The stone is thus carried quickly past the fixed scraper, and the operation may be repeated several times until the required finish is given. Instead of fixing the scraping tool in a slot it may be held in a slide rest fixed to the standard *g*, so as to be conveniently adjusted. Instead of fixing the stone upon the slide, it may be fixed on a plate or bed mounted on a pivot on *f′* acting as a turntable. The stone thereon being turned round may be cut cylindrically, or by turning it through any part of a revolution its edges may be cut with a curve, or dressed to any desired angles.

Fig. 2305 is an enlarged section of a modified form of the machine, and is employed when it is desired to mould a stone on both edges, or to saw it across from both edges at one operation. The bed of the machine supports at *f* a sliding table moved along it by the travelling screw. *b*, *b* are vertical shafts, one at each side of the machine, driven either by repetition of the gearing, Figs. 2303, 2304; or one of them may be so driven and the other geared to it that they may revolve in opposite directions. Each of these shafts is fitted with a rotating cutter barrel, or when the stone has to be sawn, with circular saws *m*, *m*, which nearly touch each other in the middle. The stone *l* being placed on the sliding table *f*, which advances it while the saws *m m* revolve, is separated by their action. The saws can be adjusted vertically on these shafts, so as to separate the stone at any desired level.

2303.





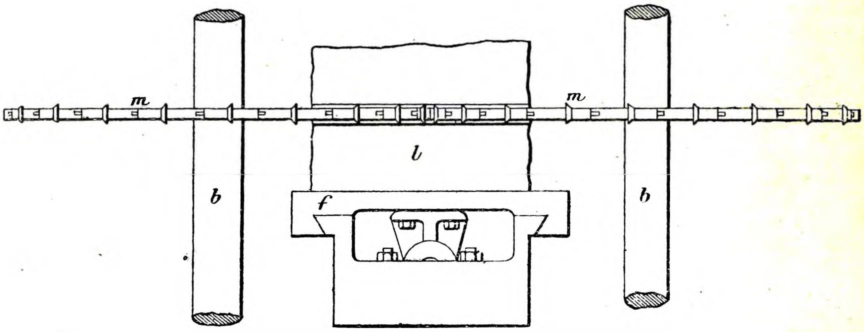
2304.

The teeth or cutters for the saws are cylindrical tapering bolts, Figs. 2311, 2312, with flat heads, which do the cutting. A powerful machine on this principle is an arrangement of a pair of saws, each 5 ft. 4 in. in diameter, that work horizontally upon upright shafts, and in their work meet each other within about an inch. The sawn slab separates readily and uniformly at the middle of the piece left uncut. Each of these saws has forty-four cutting tools round its periphery. These are carried by holders that are wedged into the outer edge of the saw plates, and have holes forged in them for the reception of the tools, as in Fig. 2312. This machine will cut about 1 ft. superficial a minute. A block of Portland stone, 5 ft. 9 in. by 4 ft. wide, can be cut into a slab of 2½ in. thick in rather less than twenty-five minutes.

Figs. 2306, 2307 are views of an apparatus for moulding stone to a circular sweep. *d* is a shaft carrying a rotating cutter; *b* is the stone fixed on a table or slide *c*, which is mounted and traverses on a bed curved to an arc of a circle. The edge of the slide *c* is cogged and geared to a rack *e*, which is made to traverse by means of a screw *f*, driven by suitable gear for reversing and altering speed. The screw being turned while the shaft revolves, the stone is cut to a sweep concentric with the curvature of the bed. The shaft may be adjusted vertically, and the stone may be blocked more or less to vary the radius of the curvature.

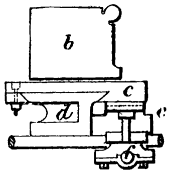
Fig. 2308 represents a side view, and Figs. 2309, 2310 a section of Hunter's rotating cutters fitted with cutting tools secured in graduated sockets. *e e* are the cutters, which are made of different depths, these lengths and depths being graduated by successive steps. When the cutters are ground, and thereby shortened to the extent of one of these steps, each is transferred to the next step in order, the relative projections of the cutters being thus maintained. By properly forming the sockets the cutters may be made of rectangular, triangular, or other convenient section.

2305.



G. Hunter has devised another apparatus in which blocks of stone, placed upon a reciprocating table, are subjected to the action of revolving and scraper tools, so as to cut their surfaces to flat or moulded forms.

2306.



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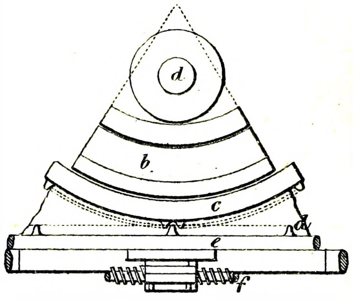
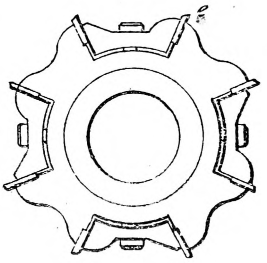


Fig. 2313 represents a plan; Fig. 2314 a side view, and Fig. 2315 an end view of this stone-working machine, Figs. 2316 to 2319 being details.

A is the main frame on which is fitted the sliding table B. On the under side of the table is a rack *b* having sloped teeth that engage with a worm, slightly tapered and fixed on a shaft *c*, which slopes downwards to the level reversing gear D at the end of the machine. By thus sloping the shaft *c*, the reversing gear can be mounted at a level sufficiently low to permit the table B to pass over it, thereby shortening the bed of the machine. E is a cross shaft on which are right and left worm-wheels *e*, *e*, that drive the upright shafts F, F, one on each side of the table, these shafts carrying the revolving cutters, Fig. 2315, arranged nearly to the outline of the moulding to be cut on the stone G. The upright shafts F, F may be mounted in sliding bearings, so that they could be set wider apart if required. On each side of the table is a column H that can be raised or lowered by a screw *h*. A cross bar I may be extended above the table, jointed to the heads of these columns, the bar having a holder *i* fitted on it for scraping or planing tools, adjustable by a

2308.



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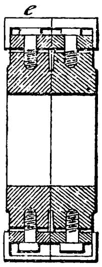
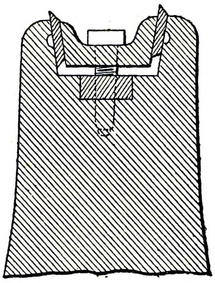
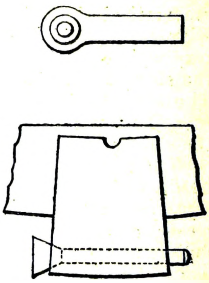


2310.

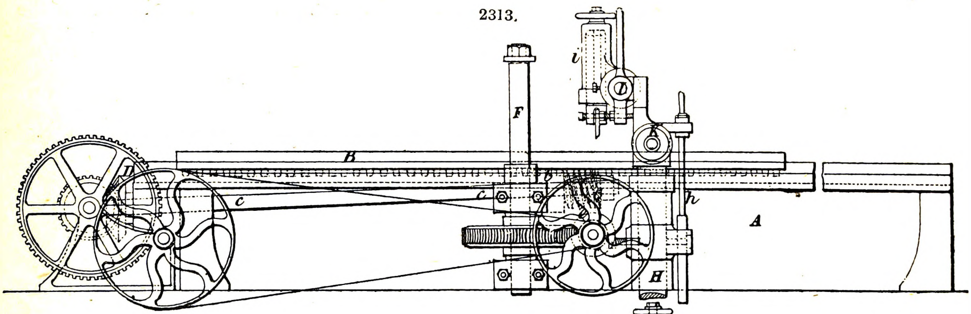


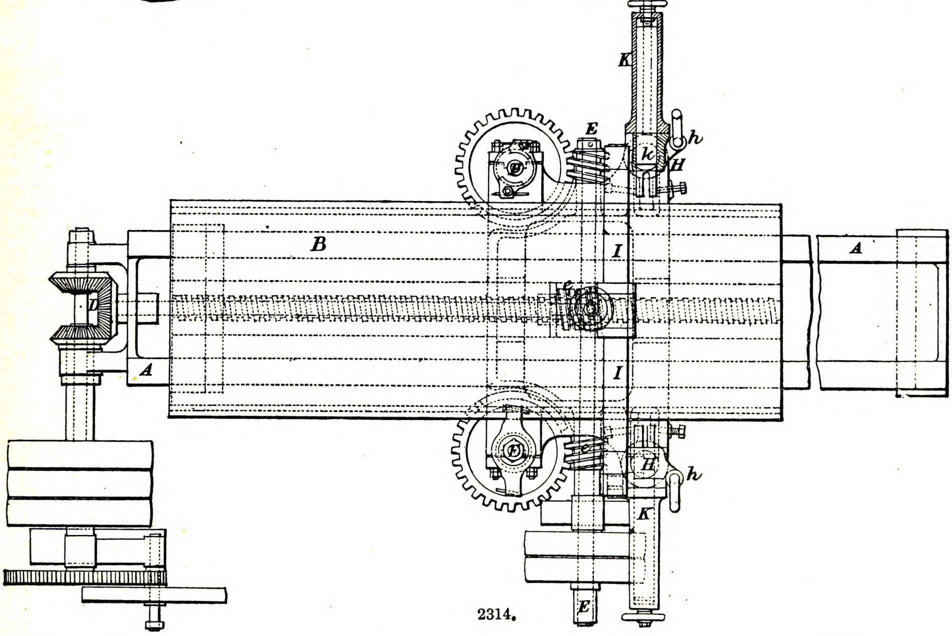
2311.



screw, as in a slide rest. K, K are tubes within which sliding stems *k* are fitted carrying also scraping or planing tools, the stems being caused to slide outwards or inwards by means of screws. The tubes K with their stems *k* and tools may be double, as in Fig. 2318, the one stem being fitted under and to one side of the other, as shown in oblique section Fig. 2319, or single stems *k* may be made with a head to receive two sets of scraping or planing tools as in Fig. 2316, a like construction applying to the stems in the holder *i*, which is here constructed as a tube with an internally sliding stem, in a similar manner to the tubes K.

2313.





2314.

2315.

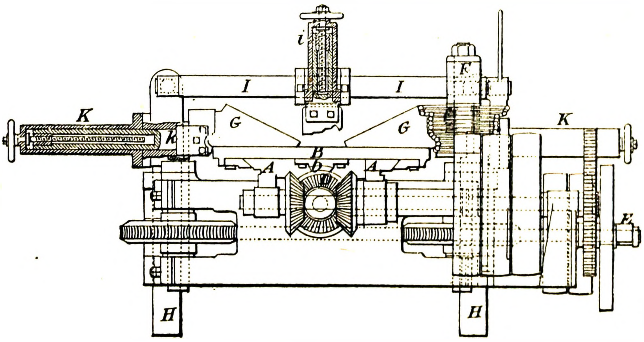
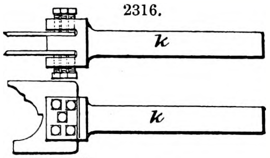


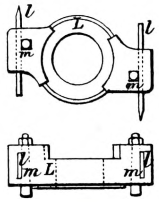
Fig. 2317 is a plan and side view of a holder for the revolving cutters. It consists of a head L which is fixed on the revolving cutter shaft. Through slots in this head are passed the cutters *l*, *l*, which are secured by wedge keys *m*, *m*, drawn up by nuts. The faces of the keys *m* next the cutters *l* are made with an edge which, when the keys are drawn tight up, cuts slightly into the metal of the cutter, preventing it from shifting.

The stone-dressing machine devised by J. D. Brunton and F. Trier, of London, which is both novel and effective, utilizes the action of circular rotating cutters, operating by rolling to chip off from the stone the inequalities of its surface.

Fig. 2320 represents in section, the chuck, or cutter carrier of this machine; and exhibits the way in which the cutters are given a determinate rotation on their own axes, at the same time that they are carried round in a circle by the revolution of the carrier; the outer edges thus describing a circular path, which may be called the track.

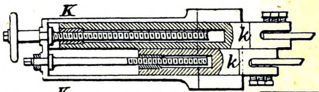
2316.

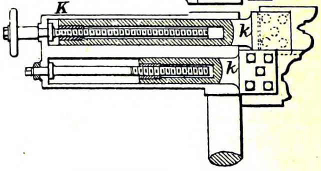




2317.

2318.

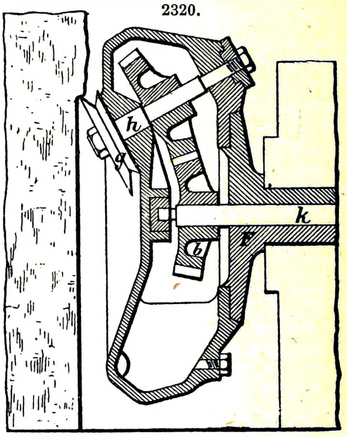




2319.

The chuck is a cast-iron circular box, bolted to the flange of the shaft F, on which it revolves. Into it are fitted the cutter spindles *h*; in number three, six, nine, or twelve, according to the size of the chuck. The cutters are fixed on their spindles by split nuts: a part of each of these nuts is a cone, which enters into the conical hole in the centre of the cutter. When screwed up the nut contracts, and grips the thread of the spindle, so that nut, cutter, and spindle become as one piece. On each spindle is keyed a bevel pinion; and all the pinions contained in a chuck gear into, and are driven by, the central bevel wheel *b*: this is keyed on the central shaft *k*, which passes through the centre of F, and receives its motion by means of a pulley.

2320.



The rates of cutter-rotation and of chuck-rotation are so adjusted relatively one to the other, that the cutter edge shall exactly roll in the track. For instance, in the case of a chuck having a track of 2 ft. diameter and cutters of 8 in. diameter, for every revolution of the chuck the cutters will make three revolutions.

Theoretically, with an exact roll of the cutter edge on the stone, there will be no attrition; and this is probably not far from being realized in practice. But coincident with the roll of the cutter, there is a forward movement of the stone, distributed over the edge of the cutter as it rolls; and to this it is probably due that there is any appreciable wear of the cutters at all.

The ordinary speed of a chuck is 300 to 350 revolutions a minute; the cutters themselves making 900 to 1050 revolutions in the same time.

The tread of a cutter, that is the length on its periphery that is in contact with the stone at any given moment, may be put at $\frac{3}{8}$ in. The duration of contact of any given tread will therefore be found, by dividing one minute by the circumference of a 2-ft. track, multiplied by 300 revolutions, and divided by $\frac{3}{8}$; or by 60,290. Thus in round figures the duration of contact is a thousandth part of a second; during which the advance of the stone will be less than the $\frac{1}{3000}$ part of an inch. The result of this small amount of attrition, and of its being distributed so rapidly and evenly over the whole circumference of the cutter is, that there is no perceptible heating, notwithstanding that the circumferential velocity of the cutters is about 2000 ft. a minute. Pulleys of different diameters are provided for the central shaft, to vary the speed of the cutters, as required by their diminished diameter consequent upon wear. The inclination of the cutters to the plane of the stone is usually 45°, but is varied to suit the character and progress of the work.

The cutters are sometimes placed in steps, or so as to cut in different planes; and several important advantages accrue from this arrangement.

It has been found that for all kinds of sandstones, grit stones, and free stones, as well as for the magnesian limestones and oolites, chilled cast-iron cutters answer perfectly. They are chilled on the outer conical face, so that, as they wear, and are ground on the lower edge or base of the cone, the cutting edge is always formed against the chilled surface. In a six-cutter chuck, dressing from 40 to 50 sq. ft. of Newcastle grit an hour, the cutters will last seven or eight hours without changing. A cutter is ground in a few minutes, by means of an ordinary grindstone and a simple mechanical appliance, and is then ready for use again. A cutter will usually last for 20 such grindings before it is worn out.

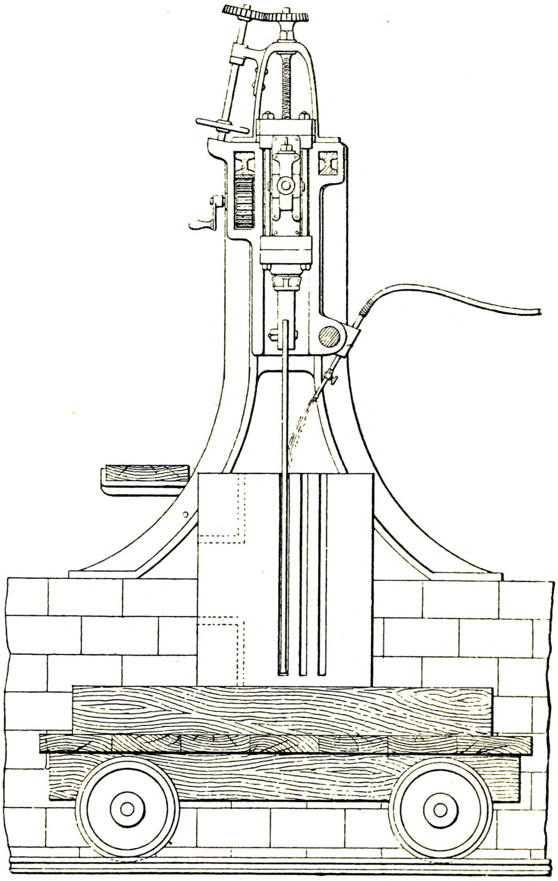
For hard limestones, steel cutters are necessary on account of the resistance presented by these stones: but the wear is insignificant. A set of cutters will last several days without changing. For granite steel cutters are also required. In the lathe a cutter will run for about 10 hours without sharpening, dressing once over 250 sq. ft. of granite. In dressing plain surfaces the wear, in the case of granite, is greater than in turning: but still moderate, the tool cost being less than that attendant upon hand labour. In dressing the softer kinds of stone, such as Newcastle grit Bramley Fall, Dumfries, Red Mansfield, and the like, the travel of the table is $\frac{1}{8}$ of an inch for each revolution of a finishing cutter. With a chuck of six cutters working in three steps, there are two finishing cutters; therefore the table travels $\frac{1}{9}$ of an inch for each revolution of the chuck, or 36 in. a minute, if the chuck makes 324 revolutions.

If a stone 2 ft. 6 in. wide, and 4 ft. 6 in. long were to be dressed, a breadth of about 9 in. each side would first be taken, and then a middle cut of 12 in. would finish it. Each cut would take, including the time occupied in raising or lowering the chuck, about 3 minutes, or 10 minutes for the whole stone, which has a superficial area of 11¼ sq. ft., this is equal to about 65 sq. ft. an hour.

Schram's stone-cutter is a machine which is used to cut slabs, paving-stones, kerb, pilasters, and similar pieces out of the rough block, a great saving of material being thereby effected.

The machine, Fig. 2321, consists of two standards erected on side walls, between which are laid rails for a tramroad. The standards are joined together at their upper extremity by two girders, one of which is furnished with teeth and forms a rack: a round bar reaches from side to side about 2 ft. below the girders. The girders and bar act as guides for the engine, which is a modification of Schram's rock drill; it travels vertically between the standards along the guides, and is moved backwards and forwards, as may be required, by a toothed wheel gearing into the rack.

2321.



At the end of the piston rod of the engine is fixed a movable cutting tool, the shape of which varies according to the work to be done.

The engine is worked by compressed air or steam, the branch between the main pipe and the engine consisting of a length of flexible tubing to allow it to travel the necessary distance between the standards.

The block of stone to be cut is placed on a trolly and wheeled between the walls, until a point in the length of the desired cut is under the cutting edge. It is then fixed firmly in position with the line of groove to be made, parallel with the guides of the engine.

The engine is started, and moved from end to end over the block of stone. As the cutting tool chips out the groove deeper and deeper, the engine is fed down towards the stone by means of a feed screw.

In order to wash away the stone dust, and keep the slot clear, a constant stream of water, regulated by a small cock and nozzle fixed to the engine, plays on the cutting tool.

The work that has been done by this machine is;

In hard granite, slab 10·764 sq. ft., cut in 3 hours.
In sandstone „ 7·53 „ „ 1 hour.
In limestone „ 5·382 „ „ 1 „

Besides the rapid cutting shown by these figures, an important result of this machine is that two surfaces are obtained, each in the same condition as if roughly ground, consequently much time and labour is saved in the subsequent dressing. A 3 horse-power boiler is sufficient to supply steam for the engine.

TRAMWAYS.

In railways the road is required to have a certain amount of spring or elasticity, to lessen the great wear and tear caused by heavy weights running at high speeds. The rails and the sleepers being bare, it is easy to pack them up when necessary.

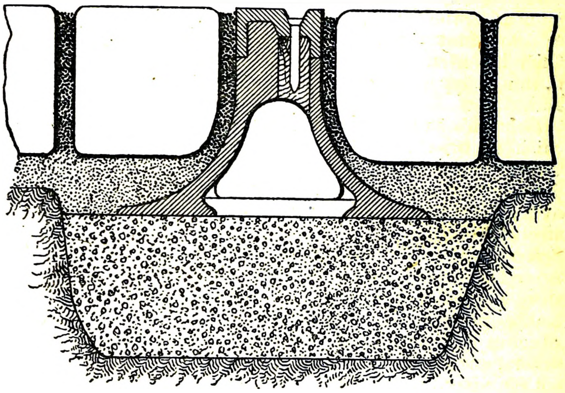
It is widely different in the case of tramways. The weights are comparatively light, the speed is very moderate, and it is impossible to pack up the rails without incurring very serious expense and inconvenience to the ordinary traffic of the road. It is therefore evident that tramways should be constructed in such a manner as to avoid the necessity of constant supervision and repair.

In order that this condition may be fulfilled, it is necessary that the stability of the foundation of the tramway should be exactly similar and equal to that of the pavement of the street. Granite pavement is practically unyielding when laid on a good foundation. It therefore follows that the foundation of the tramrail should be continuous and equally unyielding, and at the same time of such tenacity as to allow extremely heavy loads to pass over it without liability to fracture. If any want of uniformity should exist between the stability of the rail and the adjacent pavement, unequal vibration would be the result, which would tell most seriously upon both the rail and the pavement. The rails should be supported upon imperishable material, otherwise periodical removals would be necessary.

No mechanical fastenings should be introduced, or if they are indispensable, they should be as few in number as possible, and of the simplest and most effective kind. The rail should be maintained exactly level with the pavement of the street adjacent to it; if this is the case, no damage or accident can occur to the ordinary traffic.

It is necessary that the pavement adjacent to the rails should be capable of easy repair. This is occasioned by the fact that this portion of the road is subjected to undue wear and tear, by the wheels of ordinary vehicles in their endeavours to keep the rails, and might to some extent be obviated by the alteration of the gauge from 4 ft. 8½ in. to 4 ft., and then it would be impossible to alter the gauge of the wheels of ordinary vehicles to fit the rails, which has actually been done in many places. The groove must be as small as possible, and the rail narrow.

2322.



Some of the methods that have been devised for the construction of tramways will be reviewed, and for these, as well as the foregoing details, we are indebted to a paper written by J. H. Lynde.

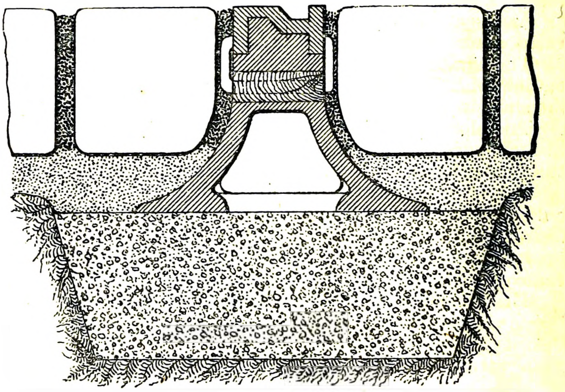
Tramways may be divided into classes, namely, those in which the rail is supported upon chairs placed at intervals, and those in which the rail is supported upon a continuous longitudinal bearing.

When supported at intervals, the rail must be of such a section as will ensure sufficient strength to carry the passing load between the points of support.

Fig. 2322 gives the section of rail usually rolled for this purpose. The weight is about 46 lb. a lineal yard.

The chairs, one yard apart, are of cast iron. In the arrangement Fig. 2322 the tramrail is pinned down through the groove, into a hole in the upper part of the chair that has been plugged with ash. In Fig. 2323 the rail is held in its place by side fastenings, which are nailed crosswise into a hole in the chair, into which an ash plug has been previously fitted.

2323.



In laying a tramway by this method, it is necessary to excavate along the centre line of each rail, at intervals of one yard from centre to centre, a series of holes 16 in. or 18 in. square, and 18 in. deep from the surface of the road. These holes are then filled with concrete to the level of the bottom of the chair, which is placed upon it. Concrete is filled in round the chair to receive the paving, and also under the intermediate portion of the rail. The rail is placed in position and spiked down, and the paving made good up to it. It is found better to remove the paving between the rails during construction, as the sets have to be picked and cut to fit the spaces adjoining the rail.

The paving abutting the rail is here upon a variable foundation, that nearest to the chairs being upon concrete, while that between the chairs rests upon the old foundation of the street. This variable foundation must be a disadvantage.

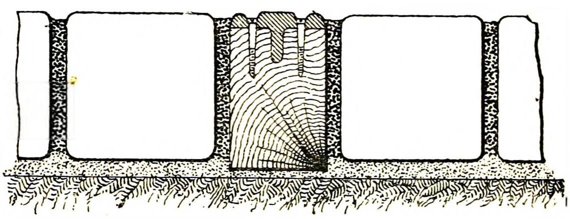
It may appear that the rail is supported between the chairs by a narrow thin bed of concrete, but this is not the case; and if it were possible to ensure the complete and solid bedding of the rail, which cannot be accomplished, the vibration would in a few weeks completely disintegrate the concrete and render it worthless.

The foregoing may be taken as an example of the best form of tramway of its class, and it has been adopted with slight variations at Leeds, Sheffield, and Bristol.

In comparing this system with the conditions laid down, it will be seen: the stability of the rail varies from that of the pavement of the street, and that vibration must occur between the rail and the adjacent pavement. Cast iron is very durable, and will last a long time, but the pins and the fastenings being of wrought iron, under the conditions in which they are placed, their durability is limited. The fixing of the rail being dependent upon pins and fastenings, they are liable to become loose, and it is practically impossible to maintain the pavement level with the rail by this method. At Leeds and other places many complaints have been made of the danger and inconvenience to the ordinary traffic arising from this cause. It is also very costly and inconvenient to repair the pavement adjacent to the rail, as it must be removed, and either the same or new setts be relaid, with all the trouble and expense of picking and cutting stones to fit the spaces. The system of laying tramways which has been most generally adopted belongs to the class in which the rail is supported upon a continuous longitudinal bearing. Lynde mentions a tramway on this principle in which each rail consisted of a flat bar, about 5½ in. wide and ½ in. thick, screwed down to a longitudinal timber sleeper. In the centre between the two outer rails was a small bridge rail turned upside down, forming a groove. This was also fastened to a longitudinal timber. A small guide wheel was attached to the front of the ordinary omnibus, and this was capable of being raised or depressed at pleasure by the driver, so that the omnibus could pass on to or off the rails as occasion required. This was in use for some years, and has its merits.

Fig. 2324 is a modification of this system. It consists of two rails, each formed of a ┳ iron with two grooves rolled in the flat side, which is placed uppermost, and the tongue of the ┳ iron is let into a groove in the timber; it is then fastened down by means of screws. The object of the two grooves is to prevent the slipping of horses passing over the rails. In place of the old central grooved rail a straight joint is made in the setts from end to end of the tramway, midway between the two rails. It is intended that the driver shall by sight keep the omnibus on the track, simply by means of the guide offered by the straight joint in the paving. In snowy or dirty weather, and after dusk, this would be almost impossible, although it is stated that the horses soon become used to the track, and finding the traction so much reduced endeavour to keep the rails without much assistance from the driver. The great disadvantages of this system are the straight joint in the paving, which is always the cause of depression; and that, in the event of steam or other motive power being introduced, the tramways would not be suitable for the traffic.

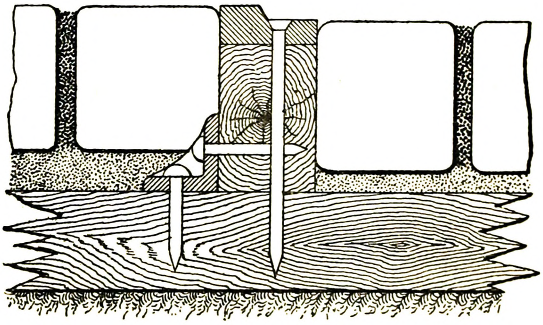
2324.



The early American lines, and those first laid in London and Birkenhead, Fig. 2325, were on continuous bearers. The longitudinal sleepers rested upon transverse sleepers placed about 4 ft. apart, and were secured to them by means of small cast-iron angle brackets and two spikes. The rail was not grooved, but rebated, and it was intended that ordinary vehicles should pass over it without inconvenience. This was found impracticable.

The improvements since made have consisted principally in introducing a concrete foundation, and in altering the section of the rail. A narrow rail with a small groove is the best form for the cars, and this section presents the least obstruction to the ordinary traffic, supposing the pavement to be kept level with the rail.

2325.



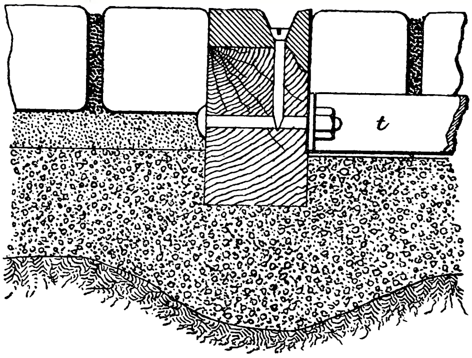
At Liverpool, Fig. 2326, longitudinal timber sleepers were laid on a bed of concrete. The upper corners of the longitudinal sleeper were rebated out to receive the rail, which was spiked down through holes in the groove. Wrought-iron tie-bars *t* were bolted to the longitudinal bearers at intervals. This system has proved insufficient for the ordinary traffic of the town.

The Southport tramway, Fig. 2327, is another example of longitudinal sleepers, but they are laid upon cross sleepers 4 ft. apart, and held in position by means of wrought-iron dogs. This tramway is of recent construction, and the ordinary traffic of the road in which it is laid is very light.

In London, Fig. 2328, longitudinal timber sleepers were laid in cast-iron chairs, about 4 ft. apart, upon a continuous bed of concrete. Small fish-plates were introduced at the junctions of the rails. Transverse tie-rods, 2¼ in. by ¼ in., held the chairs in position. The rail was spiked down through the groove. It is found that the rails soon work loose by this system. Asphalte has been used for paving between the rails of the South London tramways, but with indifferent success, the asphalte giving way at its junction with the rail. The cause of this is the unequal vibration that takes place between the rail and asphalte, which are upon different foundations.

Other London tramways were laid in the same way as at Liverpool, with the addition of cast-iron chairs to join the longitudinal sleepers.

2326.



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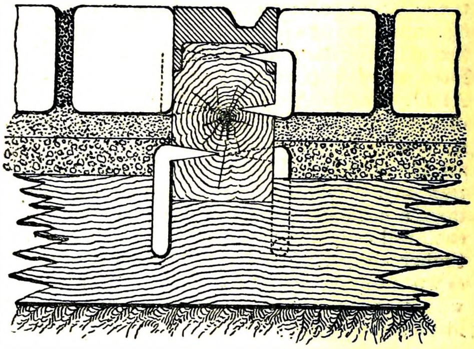
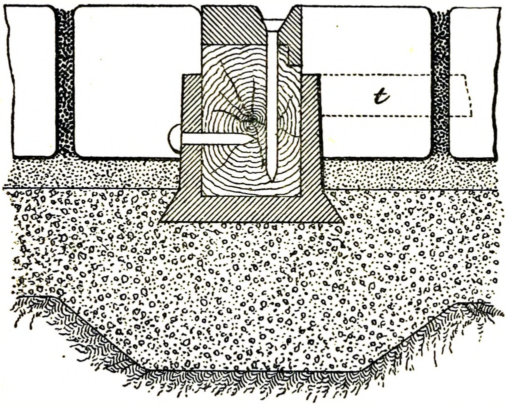


The Edinburgh tramways, Fig. 2329, were laid upon the longitudinal timber sleeper principle, but the method of fastening down the rail was by means of $\frac{5}{8}$-in. bolts passed through the groove of the rail and screwed into nuts fastened to the under side of the timber. Wrought-iron transverse ties, 2 in. by $\frac{3}{8}$ in., 4 ft. apart, were introduced. The timber was creosoted, and the bolt holes were filled with boiling tar before the bolts were driven. The rails weighed 52 lb. a lineal yard. Fish-plates, 15 in. by 3 in. by $\frac{5}{8}$ in., punched for four bolts, were placed at the junction of the rails, and the ends of the longitudinal timber sleepers were supported in cast-iron chairs. A bed of concrete, 6 in. thick, was laid underneath the sleepers and paving. Experience has proved that this system is not satisfactory. The gradients in Edinburgh are very severe, in some instances being as steep as 1 in 13.

2328.



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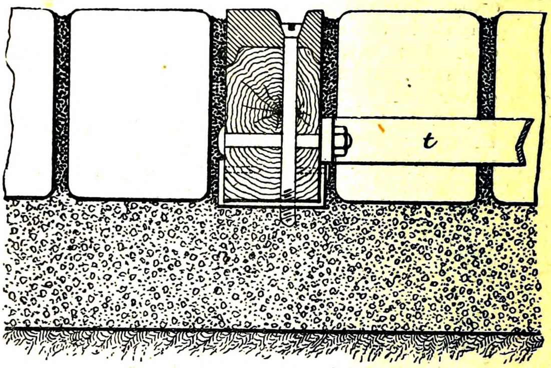
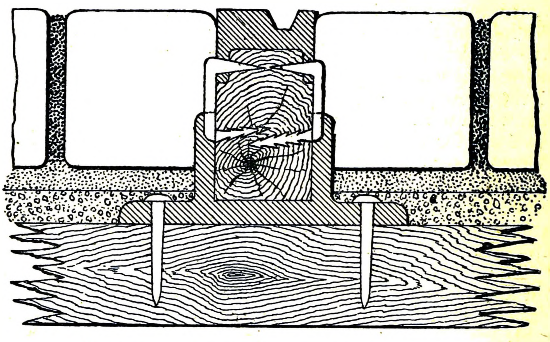


In Glasgow, Fig. 2330, a similar mode of construction was adopted. The roadway was excavated $13\frac{1}{2}$ in. deep for the full width of the tramway. Transverse sleepers, 8 ft. long by 6 in. by 4 in., were laid 3 ft. 8 in. apart. Upon these were placed cast-iron chairs to receive the longitudinal timber sleepers, 6 in. deep by 4 in. wide. The rails, weighing 60 lb. a lineal yard, were fastened to the timber by means of wrought-iron dogs about 12 in. apart. A fish-plate was placed at the junction of the rails. The spaces between the transverse sleepers were filled with concrete. On this a bed of finer concrete was laid, or in some cases bituminous concrete, composed of broken slag fresh from the blast furnace and boiling bitumen; 31 lb. weight of bitumen being mixed with 1 cubic foot of broken slag. On this a bed of sand was placed to receive the paving stones, which were run solid with boiling pitch. This was considered the best example of the longitudinal sleeper system.



On comparing these tramways, it will be found that the stability of the rail varies from that of the paving of the street, and therefore unequal vibration takes place at the junction; that timber is not a durable material, especially in damp situations, and in some countries cannot possibly be used on account of the ravages of insects.

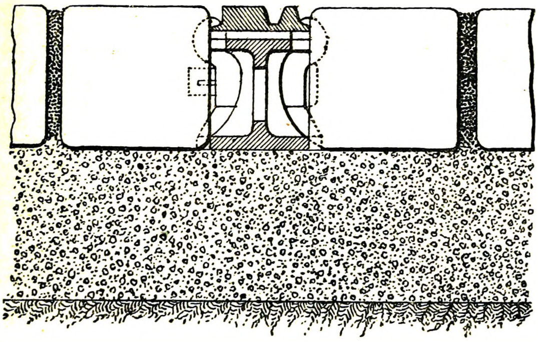
The rail is in all cases held down by pins, bolts, dogs, or other fastenings, which are liable to become loose; and it is found impossible to maintain the paving level with the rails by these methods. It is very costly and inconvenient to repair the pavement adjacent to the rail.

An attempt has been made to supersede timber sleepers by the use of cast iron, Fig. 2331. For this purpose a bed of concrete is recommended, the whole width of the tramway, and upon this a series of cast-iron bearers, each 30 in. in length, are laid. They are of I section, and are made as light as possible, weighing only from 35 lb. to 40 lb. a lineal yard. They overlap at the joints, and are fastened together by means of wrought-iron pins and cotters. The ends of the bearers are provided with lugs, cast on, and having inclined surfaces to receive the taper fillets rolled on each side of the rail. It is so arranged that at each joint in the cast-iron bearer, the key which fastens them together also secures the rail. The weight of the rail is 26 lb. a lineal yard. Ties are not absolutely necessary, but if used may be placed 6 ft. apart. It is stated that eleven miles of tramway on this system have been laid in Madras with good results. It is not probable that such a light casting as that proposed would bear the strain of the heavy loads that are constantly passing in larger cities.

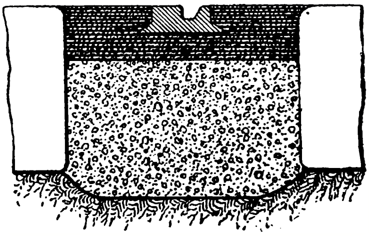
The rail is held in position by means of cast-iron lugs, and these would very probably be broken by the cross traffic.

It is not possible to pave directly up to the side of the rail, on account of the projecting foot. There must therefore be a space on each side of the rail about ½ in. wide. At the points where the clips occur, the setts cannot be laid nearer than about 1½ in to the rail. These are disadvantages, as the paving is a great support to the rail when immediately abutting it. The cast-iron bearer which is left hollow after the paving of the street is completed, would become a cesspool for water and street refuse, and injuriously affect the foundation of the pavement. Practically it would be difficult, if not impossible, to bed the cast-iron bearer evenly upon the concrete. The rail could not be removed without first taking up the surrounding pavement. It would be costly and inconvenient to repair the pavement adjacent to the rails.

2331.



2332.



Another system of continuous bearing has been recently devised, and has proved that it possesses great advantages. In laying down this tramway, Fig. 2332, the foundation of the street or road is not interfered with in any way, only those granite setts being removed which would be intersected by the grooved iron rail and an extra width of about 3 in. on either side of it. These setts are carefully taken up, without disturbing the surrounding pavement, thus leaving a shallow trench with indented sides. This space is then filled in with concrete to within 2¼ in. of the surface of the road. In twenty-four hours this is sufficiently set to receive the liquid asphalte in which the rail is imbedded, the surface of the asphalte being grooved to imitate the joints of the paving, to render the foothold secure.

It is found that asphalte will adhere with great tenacity to iron and other substances, and this property, in conjunction with the dovetailed section of the rail, renders the tramway immovable. The use of timber is altogether dispensed with, and as the rail is firmly imbedded in asphalte upon a concrete foundation, it is preserved from injury. Respecting the durability of Val de Travers asphalte, it has been proved to exceed that of the hardest granite; at the same time, being in some degree elastic, it deadens vibration and permits the free expansion and contraction of the rail under various temperatures. In addition to these advantages, in cases where it becomes necessary to remove a rail, the operation can be effected with ease, and the old asphalte taken up can be melted and used over again. Should it be required to raise the surface of the asphalte, no difficulty would be experienced in the operation, and the extra thickness added would become part of the original mass.

By this plan no special provision is necessary for laying the tramway round curves, but the same method is pursued as in straight lines, and the rail is equally secure; whereas, in cases where longitudinal timber sleepers are used, it is necessary to cut them into short lengths or bend them, either of which is detrimental to the stability of the rail.

By this system the rails may be laid in any direction, either diagonally or in curves, across any existing pavement, without having to cut the paving stones obliquely to fit against the sides of the rails, as is the case in every other system. The laying is rapid, since little obstruction to traffic is occasioned, as such a small portion of the street is interfered with. The weight of the rail used is 26 lb. a lineal yard.

The rails of a tramway should always be constructed of steel, the slight extra first cost being more than compensated for by the greater durability. It is customary to notch or corrugate the narrow edge of the upper surface of the rail, to give foothold to the horses; but this very soon wears off, and is therefore useless.

The points and crossings of tramways are very important parts of the work, and are of various descriptions.

The oldest style of switch is the movable one, which is set by the conductor, the car being stopped for the purpose. Another form still used is the fixed point, where the horses are made to pull the car in the direction it is intended to go. Both grooves for the flange of the wheel are the same depth. This is a most objectionable arrangement, as the car is seriously strained by the operation.

The most approved method of constructing points at a turn-out or passing-place is that of a fixture, but only one of the grooves is taken to the full depth at the junction of the two. Thus, when a car meets the point, the flange of the wheel invariably takes the deep groove, which is so arranged that the car always passes off to the left.

When it is necessary that a car should be able to take either route, the movable point should be adopted as being safer and causing less wear and tear to the cars.

The crossing, that is, the place where the rail of the turn-out crosses that of the main line, is the source of very considerable expense and inconvenience in renewal. The grooves are both taken to the full depth, and where they cross great wear and tear has to be borne. A hollow is the result at this point, which not only occasions concussion that sometimes snaps the axles of the car, but also causes it to leave the rails. The simplest remedy for this defect would be to let the groove die out to the surface before arriving at the point of crossing. The wheel would travel in the right direction, as the car would be guided by the other rail. In time the flange of the wheel would wear a groove, and after this the crossing would wear as long as one constructed on the ordinary principle.

Points and crossings are usually made of cast iron, but wrought iron has been used for both. Some crossings are formed of the ordinary rails, scarfed together.

An important item in the economy of tramways is that of keeping the track clean. The force necessary to move a car on clean rails is very much less than that required when the grooves are filled with dirt.

The operation has been attempted to be effected by machinery attached to the car, and also to separate trollies, but hitherto without marked success, as the apparatus has proved itself a source of damage to the rails, and practically useless. The principle of these machines has been that of a rigidly fixed scraper, which was strong enough to demolish all obstructions that came in its path, and therefore it cut off all loose projecting pins or bolts in the bottom of the groove, and in time the rails became quite loose. An apparatus has just been introduced which seems likely to answer the purpose. It consists of a revolving steel wire brush, similar to a rotary hairbrush, which cleans the grooves without injuring the fastenings, and deposits the dirt in a line some distance from the rail.

WELL SINKING AND BORING.

The operation of sinking a well is identical with that necessary in putting down a shaft for mineral, but as both the diameter and distance are usually small, the work is of a much lighter character.

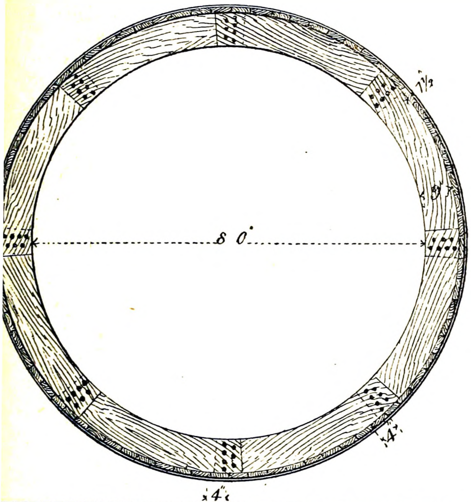
Previous to sinking it will be necessary to have in readiness a stock of buckets, shovels, picks, rope, a pulley-block or a windlass, and barrows or other means of conveying the material extracted away from the mouth of the sinking. After all the preliminary arrangements have been made, the sinking is commenced by marking off a circle upon the ground 12 or 18 in. greater in circumference than the intended internal diameter of the well. The centre of the well as commenced from must be the centre of every part of the sinking; its position must be carefully preserved and everything that is done must be true to this centre, the plumbline being frequently used to test the vertical position of the sides.

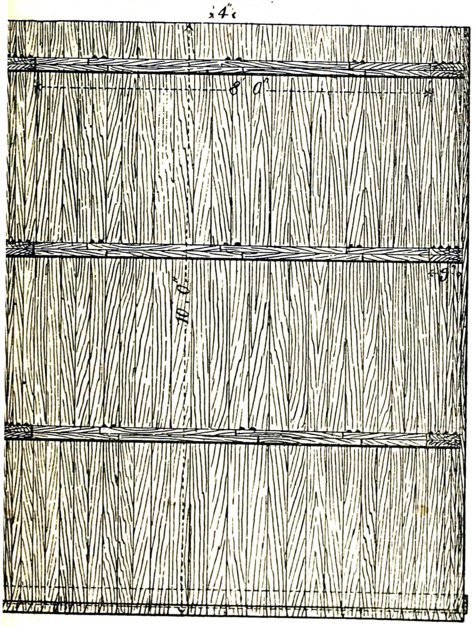
To sink a well by underpinning, an excavation is first made to such a depth as the strata will allow without falling in. At the bottom of the excavation is laid a curb, that is, a flat ring, whose internal diameter is equal to the intended clear diameter of the well, and its breadth equal to the thickness of the brickwork. It is made of oak or elm planks 3 or 4 inches thick, either in one layer fished at the joints with iron, or in two layers breaking joint, and spiked or screwed together. On this, to line the first division of the well, a cylinder of brickwork, technically called steining, is built in mortar or cement. In the centre of the floor is dug a small pit, at the bottom of which is laid a small platform of boards; then, by cutting notches in the side of the pit, raking props are inserted, their lower ends abutting against a foot-block, and their upper ends against the lowest setting, so as to give temporary support to the curb with its load of brickwork. The pit is enlarged to the diameter of the shaft above; on the bottom of the excavation is laid a new curb, on which is built a new division of the brickwork, giving permanent support to the upper curb; the raking props and their foot-blocks are removed; a new pit is dug, and so on as before. Care should be taken that the earth is firmly packed behind the steining. A common modification of this method consists in excavating to such a depth as the strata will admit without falling in. A wooden curb is laid at the bottom of the excavation, the brick steining laid upon it and carried to the surface. The earth is then excavated flush with the interior sides of the well, so that the earth underneath the curb supports the brickwork above. When the excavation has been carried on as far as convenient, recesses are made in the earth under the previous steining, and in these recesses the steining is carried up to the previous work. When thus supported the intermediate portions of earth between the sections of brickwork carried up are cut away and the steining completed.

In sinking with a drum curb, the curb, which may be either of wood or iron, consists of a flat ring for supporting the steining, and of a vertical hollow cylinder or drum of the same outside diameter as the steining, supporting the ring within it and bevelled to a sharp edge below. The rings, or ribs, of a wooden curb are formed of two thicknesses of elm plank, 1½ in. thick by 9 in. wide, giving a total thickness of 3 in.

Fig. 2333 is a plan of a wooden drum curb, and Fig. 2334 a section showing the mode of construction. The outside cylinder or drum is termed the lagging, and is commonly made from 1½-in. yellow pine planks. The drum may be strengthened if necessary by additional rings, and its connections with the rings made more secure by brackets. In large curbs the rings are placed about 3 ft. 6 in. apart. Fig. 2335 is a plan, and Fig. 2336 an enlarged segment of an iron curb. When the well has been sunk so far as the earth will stand vertical, the drum curb is lowered into it and the building of the brick cylinder commenced, care being taken to complete each course of bricks before laying another, in order that the curb may be loaded equally all round. The earth is dug away from the interior of the drum, and this together with the gradual increasing load causes the sharp lower edge of the drum to sink into the earth; and thus the digging of the well at the bottom, the sinking of the drum curb and the brick lining which it carries, and the building of the steining at the top, go on together. Care must be taken in this as in every other method, to regulate the digging so that the well shall sink vertically. Should the friction of the earth against the outside of the well at length become so great as to stop its descent, before the requisite depth is attained, a smaller well may be sunk in the interior of the first well. A well so stopped is said to

2333.





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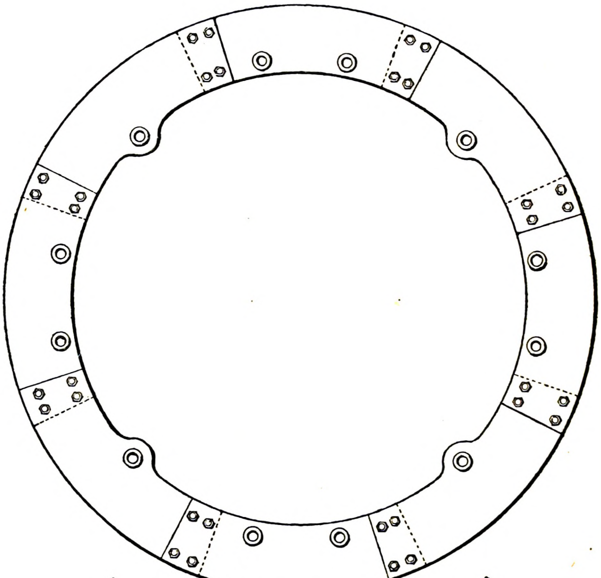
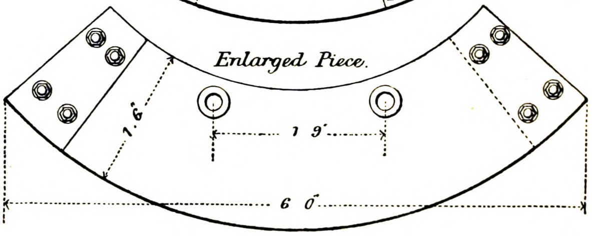




2336.

be earth-fast. This plan cannot be applied to deep wells, but is very sucessful in sandy soils where the well is of moderate depth.

The curbs are often supported by iron rods, fitted with screws and nuts, from cross timbers over the mouth of the well, and as the excavation is carried on below, brickwork is piled on above, and the weight of the steining will carry it down as the excavation proceeds, until the friction of the sides overpowers the gravitating force or weight of the steining, when it becomes earthbound; then a set-off must be made in the well, and the same operation repeated as often as the steining becomes earthbound, or the work must be completed by the first method of underpinning. When the rock to be sunk through is unstratified, or if stratified, when of great thickness, recourse must be had to the action of explosive agents. Their use has been already treated at length at pp.132,605, of this Supplement.

The system of blasting employed in well sinking is that known as the small-shot system, which consists in boring holes from 1 to 3 in. diameter in the rock to be disrupted to receive the charge. The position of these holes is a matter of the highest importance from the point of view of producing the greatest effects with the available means, and to determine them properly requires a complete knowledge of the nature of the forces developed by an explosive agent. This knowledge is rarely possessed by sinkers. Indeed, such is the ignorance of this subject displayed by quarrymen generally, that when the proportioning and placing the charges are left to their judgment, a large expenditure of labour and material will produce very inadequate results. In all cases it is far more economical to entrust these duties to one who thoroughly understands the subject.

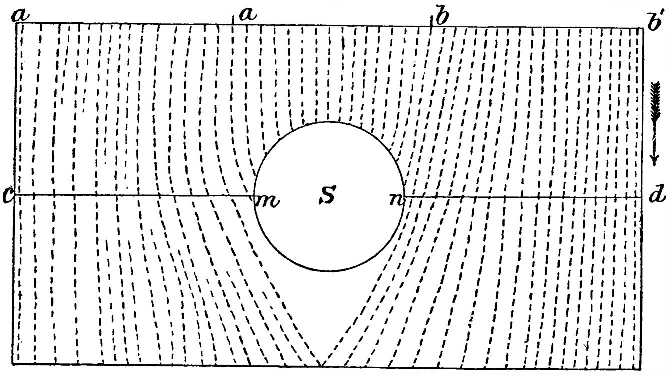
When all is ready, the sinkers, with the exception of one man whose duty it is to fire the charge, are either drawn out of the shaft, or are removed to some place of safety. This man then, having ascertained by calling and receiving a reply that all are under shelter, applies a light in the fuse, shouts "Bend away," or some equivalent expression, and is rapidly drawn up the shaft. To avoid shattering the walls of a shaft, no shot should be placed nearer the side than 12 in. The portion of stone next the wall sides of the shaft left after blasting is removed by steel-tipped iron wedges 7 or 8 in. in length. These wedges are applied by making a small hole with the point of the pick and driving them in with a mall. The sides may be then dressed as required with the pick.

After some 30 or 40 feet have been sunk the air at the bottom of the well may be very foul, especially in a well where blasting operations are being carried on, or where there is any great escape of noxious gases through fissures. Means must then be provided for applying at the surface a small exhaust fan to which is attached lengths of tubing extending down the well. Another good plan is to pass a 4 or 6 inch pipe down the well, bring it up with a long bend at surface, and insert a steam jet; a brick chimney is frequently built over the upper end of the pipe to increase the draught, and the lower end continued down with flexible tubing. With either fan or steam jet, foul air being continuously withdrawn, fresh air will rush down in its place. This is far better than dashing lime-water down the well, using a long wooden pipe with a revolving cap-head, or pouring down a vertical pipe water which escaped at right angles, the old expedients for freshening the air in a well.

A means of increasing the yield of wells, which is frequently very successful, is to drive small tunnels or headings from the bottom of the well into the surrounding water-bearing stratum.

As an example, let Fig. 2337 represent a sectional plan of a portion of the water-bearing stratum at the bottom of the shaft. This stratum is underlaid by an impervious stratum, and, consequently the water will flow continuously through the former in the direction of the dip, as shown by the arrow and the dotted lines. That portion of the stratum to the rise of the shaft S, which is included within vertical lines tangent to the circle at the points *m* and *n*, will be drained by the shaft. The breadth of this portion will, however, be extended beyond these lines by the relief to the lateral pressure afforded by the shaft, which relief will cause the fillets of water to diverge from their original course towards the shaft, as shown in the figure. Hence the breadth of drainage ground will be *a b*, and it is evident that the shaft S can receive only that water which descends towards it through this space. But if tunnels be driven from the shaft along the strike of the stratum, as at *m c*, *n d*, these tunnels will obviously intercept the water which flows past the shaft. By this means the drainage ground is extended from *a b* to *a' b'*, and the yield of the well proportionately increased.

2337.



It should be remarked that when the strata is horizontal or depressed in the form of a basin that is, when it partakes more of the character of a reservoir than a stream, the only use of tunnels is to facilitate the ingress of water into the shaft, and in such case they should radiate from the shaft in all directions. They are also of service in case of accident to the pumps, as the time they take to fill up allows of examination and repairs being made in that time to the pumps, which could not be inspected if the engines stopped pumping and the water rose rapidly up the shaft.

The size of the headings is usually limited by the least dimensions of the space in which miners can work efficiently, that is, about 4½ ft. high and 3 ft. wide. The horse-shoe form is generally adopted for the sides and top, the floor being level, for the drawing off of the water by the pumps is quite sufficient to cause a flow, unless of course the dip of the stratum in which the tunnels are driven is such as to warrant an inclination. Where there is any water it is not possible to drive them with a fall, for the men would be drowned out.

The foregoing remarks do not apply to headings driven in the chalk, where it is the usual practice to select the largest feeder issuing from a fissure and follow that fissure up, unless the heading is merely to serve as a reservoir, when the direction is immaterial.

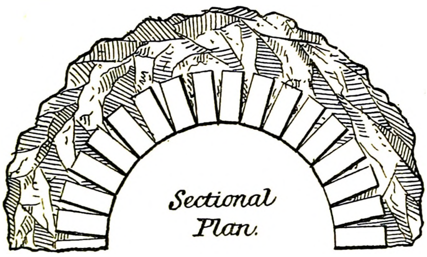
The sides of wells usually require lining or steining, as it is termed, with some material that will prevent the loose strata of the sides of the excavation falling into the well and choking it.

Brick steining is executed either in bricks laid dry or in cement, in ordinary clay 9-in. work being used for large wells, and half-brick, or 4½ in. work, for small wells.

Figs. 2339 and 2338 show the method of laying for 9-in. work, and Fig. 2340 for 4½ in. The bricks are laid flat, breaking joint; and, to keep out moderate land-springs, clay-puddle or concrete is often introduced at the back of steining. For most purposes concrete is the best, as, in addition to its impervious character, it adds greatly to the strength of the steining. A ring or two of brickwork in cement is often introduced at intervals, varying from 5 ft. to 12 ft. apart, to strengthen the shaft and facilitate the construction of the well.

Too much care cannot be bestowed upon the steining; if properly executed it will effectually exclude all objectionable infiltration, but, badly made, it may prove a source of trouble and annoyance. Half the wells condemned on account of sewage contamination really fail because of bad steining.

2338.



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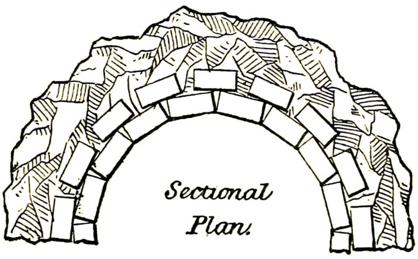
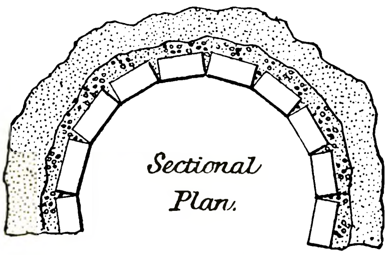


The materials that have been successfully used in this work are brick, stone, timber, and iron. Each description of material is suitable under certain conditions, while in others it is objectionable. Brickwork, which is universally used in steining wells in England, not unfrequently fails in certain positions, through admitting impure water when such water is under great pressure, or from the work becoming disjointed from settlement due to the drainage of a running sand-bed, or the collapse of the well. Stone of fair quality, capable of withstanding compressive strains, is good in its way; but, inasmuch as it requires a great deal of labour to fit it for its place, it cannot successfully compete with brickwork in the formation of wells, more especially as it has no merits superior to those of brick when used in such work; however, if in any locality, by reason of its cheapness, it can be used, care should be taken to select only such as upon test absorb the least quantity of moisture; indeed, in all cases it is a point of great importance in dying the nature of the materials used in the construction of wells, to select those which are likely to be most durable, and at the same time preserve the purity of the water contained in the well.

2340.



Timber is objectionable as a material to be used in the lining of wells, on account of its liability to decay, when it not only endangers the construction of the well, but also to some extent fouls the water. It is very largely used under some circumstances, especially in the preliminary operations in sinking. It is also successfully used in lining the permanent shafts of the salt wells of Cheshire, and will continue entire in such a position for a great number of years, as the brine seems to have a tendency to preserve the timber and prevent its decay. Iron is of modern application, and is a material extensively employed in steining wells; and, as it possesses many advantages over materials ordinarily used, its use is likely to be much extended. It is capable of bearing great compressive strains, and of effectually excluding the influx of all such waters as it may be desirable to keep out, and is not liable to decay under ordinary circumstances. Numerous instances are on record where recourse has been had to the use of iron cylinders, when it was found that four or five rings of brickwork, set in the best cement failed to keep out brackish waters; and, if the original design had provided for the introduction of these cylinders, it would have reduced the cost of the well very materially.

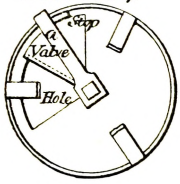
The well sinker has often, in executing his work, to contend with the presence of large volumes of water, which, under ordinary circumstances, must be got rid of by pumping; but by the introduction of iron cylinders, which can be sunk under water, the consequent expense of pumping is saved.

When sinking these cylinders through water-bearing strata various tools are used to remove the soil from beneath them. The principal is the mizer, which consists of an iron cylinder with an opening on the side and a cutting lip, and which is attached to a set of boring rods and turned from above.

The valve in the old form of mizer is subject to various accidents which interfere with the action of the tool; for instance, pieces of hard soil or rock often lodge between the valve and its seat, allowing the contents to run out whilst it is being raised through water. To remedy this defect, Thomas Docwra, designed the improved mizer, shown of the usual dimensions in Figs. 2341 to 2346; Fig. 2341 being a plan at top, Fig. 2342 an elevation, Fig. 2343 a plan at bottom, Fig. 2345 a section, Fig. 2344 a plan of the stop *a*, and Fig. 2346 a plan of the valve. It consists of an iron cylinder, conical-shaped at bottom, furnished with holes for the escape of water, and attached to a central shank by means of stays. The shank extends some 7 in. beyond the bottom, and ends in a point, while the upper part of the shank has an open slot, to form a box-joint, Fig. 2342, with the rods. The conical bottom of the mizer has a triangular-shaped opening; on the outside of this is fitted a strong iron cutter, and on the inside a properly shaped valve, seen in section and plan in Figs. 2345 and 2346. When the mizer is attached to and turned by means of the boring rods, the débris, sand, or other soil to be removed, being turned up by the lip of the cutter, enters the cylinder, the valve whilst the mizer is filling, resting against a stop. After the mizer is charged, which can be ascertained by placing a mark upon the last rod at surface and noting its progress downwards, the rods are reversed and turned once or twice in a backward direction; this forces the valve over the opening, and retains the soil safely in the tool.

2341.

Plan at Top



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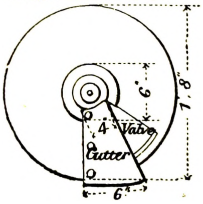
Plan at Bottom



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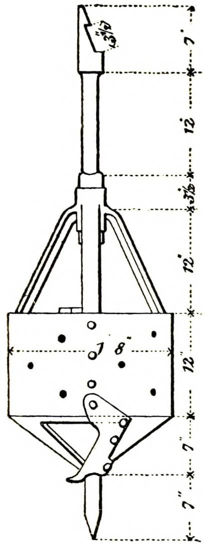

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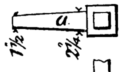

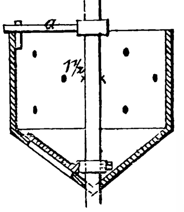

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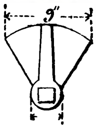

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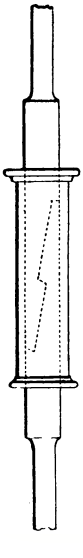

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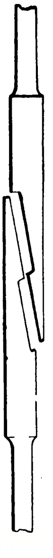

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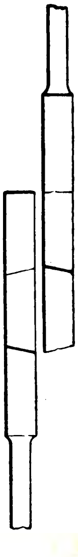

Fig. 2350 is a pot mizer, occasionally used in such soils as clay mixed with pebbles. There is no valve, as the soil is forced upward by the worm on the outside, and falls over the edge into the cone.

Mizers are fastened to the rods by means of the box-joint, Figs. 2347 to 2349, as a screw-joint would come apart on reversing.

As many as five or six different-sized mizers, ranging from 1 ft. 6 in. to 9 ft. in diameter, can be used successively, the smallest commencing the excavation, and the larger ones enlarging it until it is of the requisite size.

As an accessory, a picker, shown by the three views, Figs. 2351 to 2353, Fig. 2352 indicating its correct position when in operation, is employed where the strata is too irregular or compact to be effectually cleared away by the cutter of the mizer. The picker is fixed upon the same rods above the mizer, and is used simultaneously, being raised and lowered with that tool.

The cutting end of the picker is frequently replaced by a scratcher, Figs. 2354, 2355. This useful tool rakes or scratches up the débris thrown by the mizer beyond its own working range, and causes it to accumulate in the centre of the sinking, where it is again subjected to the action of the mizer.

Certain common methods of boring have been already referred to in this Dictionary. The Chinese method has been generally disused, iron or wood rods substituted in the place of the rope, and a variety of augers and chisels instead of the simple chisel, with appliances for clearing the bore-hole of débris. Figs. 2356 to 2373 show examples of an ordinary set of well-boring tools. Fig. 2358 is a flat chisel; Fig. 2359 a V-chisel; and Fig. 2360 a T-chisel. These chisels are made from wrought-iron, and when small are usually 18 in. long, $2\frac{1}{2}$ in. extreme breadth, and weigh some $4\frac{1}{2}$ lb., the cutting edge being faced with the best steel. They are used for hard rocks, and whilst in operation need carefully watching that they may be removed and fresh tools substituted when their sides are sufficiently worn to diminish their breadth. If this circumstance is not attended to the size of the hole decreases, so that when a new chisel of the proper size is introduced it will not pass down to the bottom of the hole, and much unnecessary delay is occasioned in enlarging it. In working with the chisel, the borer keeps the tiller, or handles, in both hands, one hand being placed upon each handle, and moves slowly round the bore, in order to prevent the chisel from falling twice successively in the same place, and thus preserve the hole circular. Every time a fresh chisel is lowered to the bottom it should be worked round in the hole, to test whether it is its proper size and shape; if this is not the case the chisel must be raised at once and worked gradually and carefully until the hole is as it should be. The description of strata being cut by the chisel can be ascertained with considerable accuracy by a skilful workman from the character of the shocks transmitted to the rods.

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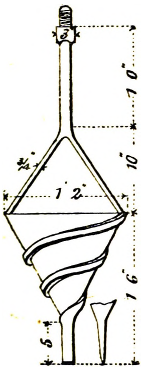

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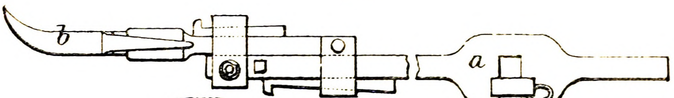

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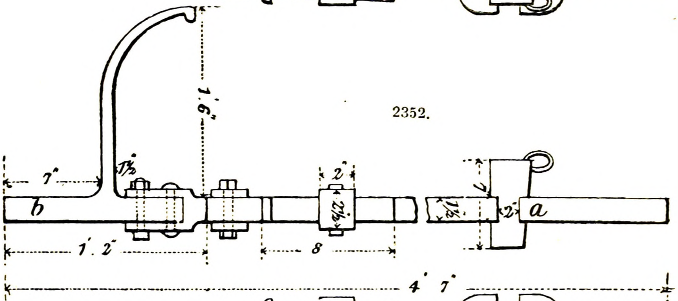

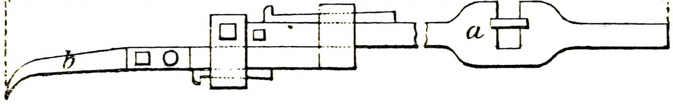

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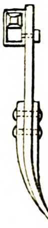

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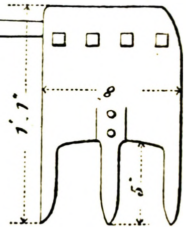


When working in sandstone there is no adherence of the rock to the chisel when drawn to the surface, but with clays the contrary is the case. Should the stratum be very hard, the chisel may be worn and blunt before cutting three-quarters of an inch, it must therefore be raised to the surface and frequently examined; however, 7 or 8 inches may be bored without examination, should the nature of the stratum allow of such progress being made.

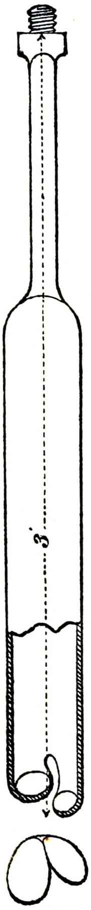
Ground-augers, Figs. 2356, 2357, 2362, are similar in action to those used for boring wood, but differ in shape and construction. The common earth-auger, Fig. 2356, is 3 ft. in length, having the lower two-thirds cylindrical. The bottom is partially closed by the lips, and there is an opening a little up one side for the admission of soft or bruised material. Augers are only used for penetrating soft rock, clay, and sand, and their shape is varied to suit the nature of the strata traversed, being open and cylindrical for clays having a certain degree of cohesion; conical, and sometimes closed, in quicksands. Augers are sometimes made as long as 10 ft., and are then very effective if the strata is soft enough to permit of their use.

The shell is made from 3 ft. to $3\frac{1}{2}$ ft. in length, of nearly the same shape as the common auger, sometimes closed to the bottom, Fig. 2362, or with an auger nose, Fig. 2357; in either case there is a clack or valve placed inside for the purpose of retaining borings of a soft nature or preventing them from being washed out in a wet hole.

Figs. 2363, 2365 are wad-hooks for withdrawing stones, and Fig. 2364 a worm-auger.

The crow's-foot, Fig. 2361, is used when the boring rods have broken in the bore-hole, for the purpose of extracting that portion remaining in the hole; it is the same length, and at the foot the same breadth, as the chisels. When the rods have broken, the part above the fracture is drawn out of the bore-hole, and the crow's-foot screwed on in place of the broken piece. When this is lowered down upon the broken rod, by careful twisting the toe is caused to grip the broken piece with sufficient force to allow the portion below the fracture to be drawn out of the bore-hole. A rough expedient is to fasten a metal ring to a rope and lower it over the broken rod, when the rod cants the ring, and thus gives it a considerable grip; this is often very successful. Fig. 2363 is a worm used for the same purpose. A bell-box, Fig. 2366, is frequently employed for drawing broken rods; it has two palls fixed at the top of the box, which rise and permit the end of the rod to pass when the box is lowered, but upon rising the palls fall and grip the rod firmly. A spiral angular worm, similar to Fig. 2363, is also applied for withdrawing tubes.

2356.



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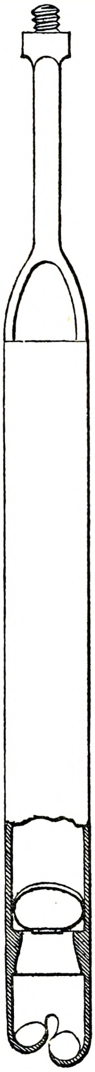

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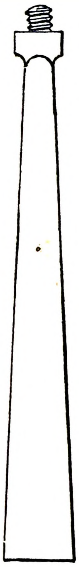

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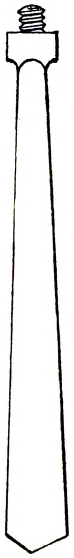

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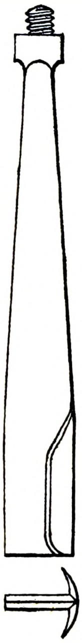

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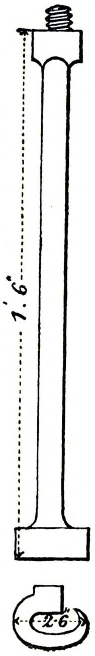

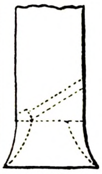

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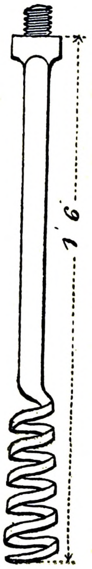

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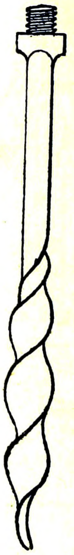

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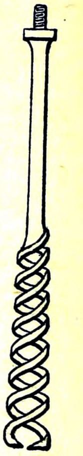
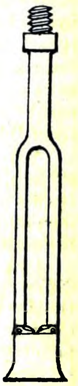


Of these withdrawing tools the crow is the safest and best, as it may be used without that intelligent supervision and care absolutely necessary with the worms and wadhooks, or the bell-box.

2366.



The boring rods, Figs. 2367, 2368, are in 3, 6, 10, 15, or 20 feet lengths, of wrought-iron, preferably Swedish, and are made of different degrees of strength, according to the depth of the hole for which they are required; they are generally 1 in. square in section; at one end is a male and at the other end a female screw, for the purpose of connecting them together. The screw should not have fewer than six threads, and have a bevelled shoulder. One of the sides of the female screw frequently splits and allows the male screw to be drawn out, thus leaving the rods in the hole. By constant wear, also, the screw may have its thread so worn as to become liable to slip. Common rods, being most liable to accident, should be carefully examined every time they are drawn out of the bore-hole, as an unobserved failure may occasion much inconvenience, and even the loss of the bore-hole.

In addition to the ordinary rods there are short pieces, varying from 6 in. to 2 ft. in length, which are fixed at the top as required, for adjusting the rods at a convenient height.

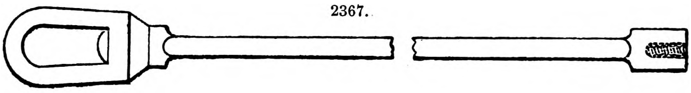
Fig. 2369 is a hand-dog; Figs. 2370 and 2371 a lifting dog; Fig. 2372 the tillers or handles by which the workmen impart a rotary motion to the tools. The tillers are clamped to the topmost boring rod, at a convenient height for working. Fig. 2367 a top-rod with shackle; Fig. 2373 a spring hook. When in use this should be frequently examined and kept in repair.

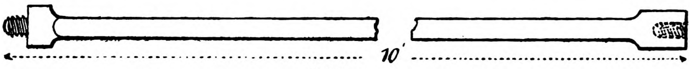
Lining tubes are employed to prevent the bore-hole falling in through the lateral swelling of clay, strata, or when passing through running sand. The tubes are usually of iron, of good quality, soft, easily bent, and capable of sustaining an indent without fracture. Inferior tubes occasion grave and costly accidents, which are frequently irreparable, as a single bad tube may endanger the success of an entire boring.

Wrought-iron tubes with screwed flush joints, Fig. 2374, are to be recommended, but they are supplied brazed, or riveted, Fig. 2375, and can be fitted with steel driving collars and shoes. Cast-iron tubes are constantly applied; they should have turned ends, with wrought-iron collars and countersunk screws.

Cold-drawn wrought-iron tubes have been used, and are very effective as well as easily applied, but their relatively high cost occasions their application to be limited.

2367.

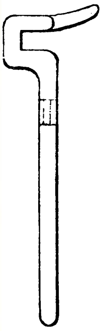




2368.

Fig. 2376 shows a stud-block, which is used for suspending tubing, either for putting it down or for drawing it up. It consists of a block made to fit inside the end of the tube, and attached to the rods in the usual way. In the side of the block is fixed an iron stud for slipping into a slot, similar to a bayonet joint, cut in the end of the tube, so that it may be thus suspended. Figs. 2377 to 2379 show various forms of spring darts, and Fig. 2380 a pipe-dog, for the same purpose. Sometimes a conical plug, with a screw cut around the outside for tightening itself in the upper end of the tube, is used for raising and lowering tubing. Figs. 2381, 2382 are of tube clamps, and Fig. 2383 tongs for screwing up the tubes.

2369.



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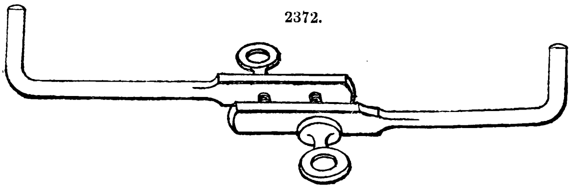

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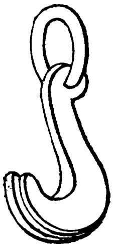

2371.

Fig. 2384 is a pipe-dolly, used for driving the lining tubes; the figure shows it in position ready for driving.

When a projection in the bore-hole obstructs the downward course of the lining tubes, the hole can be enlarged below the pipes by means of a rimer, Fig. 2385. It consists of an iron shank, to which is bolted two thin strips bowed out into the form of a drawing pen. The rimer is screwed on to the boring rods, and forced down through the pipes; when below the last length of pipe, the rimer expands, and can then be turned round, which has the effect of scraping the sides and enlarging

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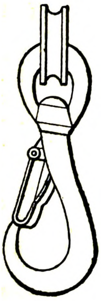

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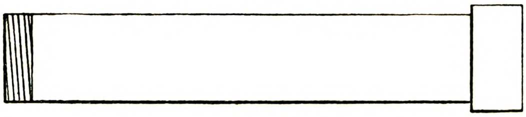

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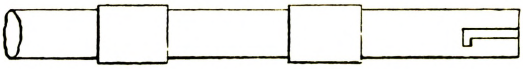

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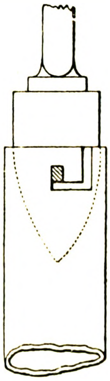
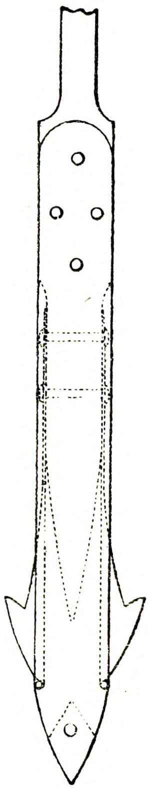


that portion of the hole subject to its operation. Fig. 2386 is of an improved form of rimer, termed a riming spring. It will be seen that this instrument is much stronger than the ordinary rimer, in consequence of the shank being extended through its entire length, thus rendering the scraping action of the bows very effective, whilst the slot at the foot of the bows permits of its introduction into and withdrawal from, the tubing.

2377.



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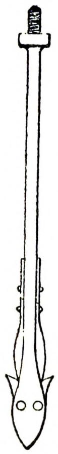

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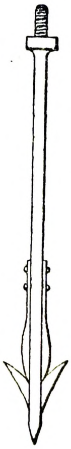

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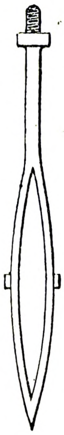

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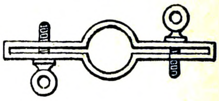

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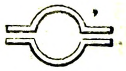

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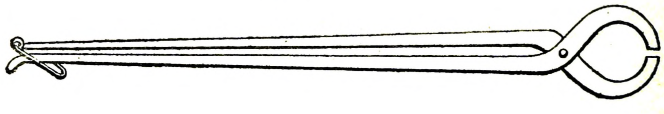
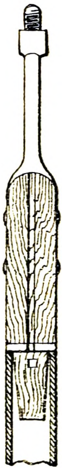


In England, for small works, the entire boring apparatus is frequently arranged as in Fig. 2387, the tool being fixed at the end of the wrought-iron rods instead of at the end of a rope, as in the Chinese method. Referring to Fig. 2387, A is the boring tool; B the rod to which the tool is attached; D D the levers by which the men E E give a circular or rotating motion to the tool; F, chain for attaching the boring apparatus to the pole G, which is fixed at H, and by its means the man at I transmits a vertical motion to the boring tool.

The sheer-legs, made of sound Norway spars not less than 8 in. diameter at the bottom, are placed over the bore-hole for the purpose of supporting the tackle K K for drawing the rods out of or lowering them into the hole, when it is advisable to clean out the hole or renew the chisel. It is obvious that the more frequently it is necessary to break the joints in drawing and lowering the rods, the more time will be occupied in changing the chisels, or in each cleaning of the hole; and as the depth of the hole increases, the more tedious will be the operation. It therefore becomes of much importance that the rods should be drawn and lowered as quickly as possible, and to attain this end as long lengths as practicable should be drawn at each lift. The length of the lift or off-take, as it is termed, depending altogether upon the height of the lifting tackle above the top of the bore-hole, the length of the sheer-legs for a hole of any considerable depth should not be less than 30 to 40 ft., and they usually stand over a small pit or surface-well, which may be sunk, where the clay or gravel is dry, to a depth of 20 or 30 ft. From the bottom of this pit, the bore-hole may be commenced, and here will be stationed the man who has charge of the bore-hole while working the rods.

The arrangement, Fig. 2388, is intended for either deep or difficult boring. A regular scaffolding is erected, upon which a platform is built. The boring chisel A is, as in the last instance, coupled by means of screw couplings to the boring rods B. At each stroke, two men stationed at E E turn the rod slightly by means of the tiller D D. A rope F, which is attached to the boring tool, is passed a few times round the drum of a windlass G, the end of the rope being held by a man at I. When the handles are turned by the men at L L, the man at I pulls at the rope, and the friction between the rope and the drum of the windlass is then sufficient to raise the rods and boring tool; but as soon as the tool has been raised to its intended height, the man at I slackens his hold upon the rope; and as there is insufficient friction on the drum to sustain the weight of the boring tools, they fall. By a repetition of this operation the well is bored, and after it has been continued a sufficient length of time, the tiller is unscrewed, and a lifting dog, attached to the rope from the windlass, is passed over the top of the rods, and then a short top-rod with a shackle is screwed on. The two men at the windlass draw up the rods as far as the height of the scaffolding or sheer-legs will allow, when a man at E, Fig. 2388, by passing a hand-dog or a key upon the top of the rod under the lowest joint drawn above the top of the hole, takes the weight of the rods at this joint, the men at L having lowered the rods for this purpose; with another key the rods are unscrewed at this joint, the rope is lowered again, the lifting dog put over the rod, another top-rod screwed on, the rods lifted, and the process continued until the chisel is drawn from the hole and replaced by another, or, if necessary, replaced by some other tool.

2384.



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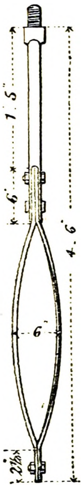

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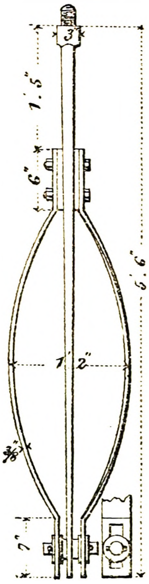


When a deep boring is undertaken, direct from the surface, the operation had best be conducted with the aid of a boring sheer frame. This consists of a framework of timber balks, upon which are erected four standards 27 ft. in height and 9 in. × 1 ft. thick, 3 ft. 8 in. apart at bottom, and 1 ft. 2 in. at top. The standards are tied by means of cross pieces, upon which shoulders are cut which fit into mortise holes, and are fastened by means of wooden keys, the standards being surmounted by two head pieces 5 ft. long, mortised and fitted. Upon the head pieces two independent cast-iron guide pulleys are arranged in bearings: over these pulleys are led the ends of two ropes coiling in opposite directions upon the barrel of a windlass moved by spur gearing, and having a ratchet stop attached to a pair of diagonal timbers, connected with the left-hand legs or standards of the sheers, near the ground. These ropes are used for raising or lowering the lengths of the boring rod.

Eight feet below the bearings of the top pulleys, a pair of horizontal traverses is fixed across the frame, supporting smaller pulleys mounted on a cast-iron frame, which is capable of motion between horizontal wooden slides. Over these pulleys is led a rope from a plain windlass fixed to the right-hand legs of the frame, to be used for raising or lowering the shell to extract the débris or rubbish from the hole.

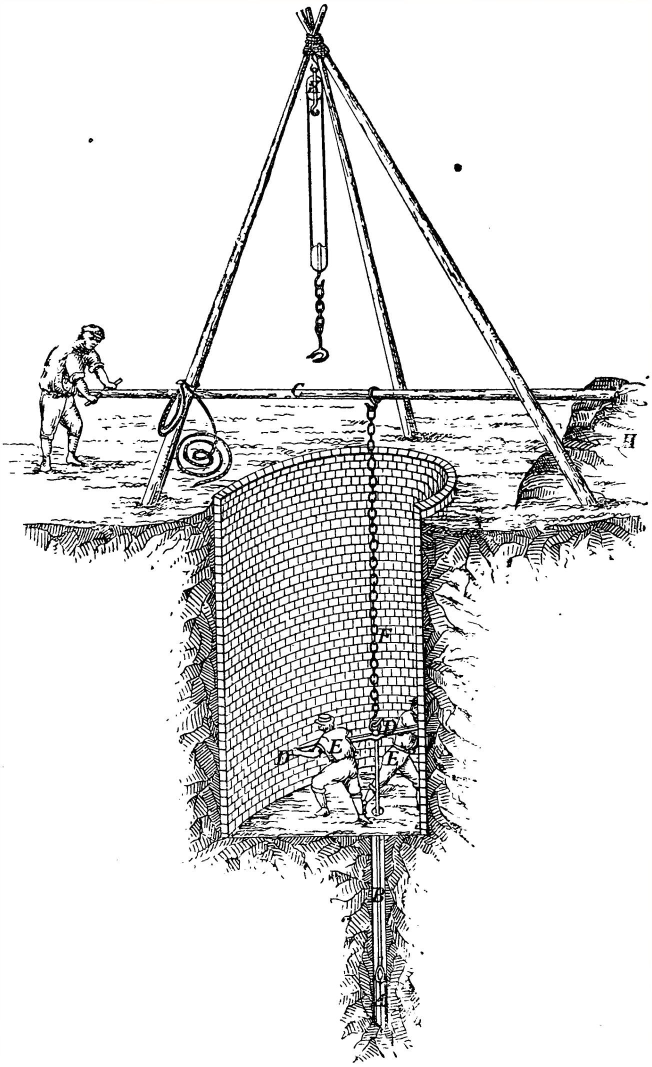
The lever, 15 ft. long, and 9 in. × 6 in. in section, is supported by an independent timber frame. It has a cast-iron cap, fastened by means of two iron straps, cast with lugs through which bolts are passed, these being tightened with nuts in the ordinary manner. The bearing-pins at *a* are 1½ in. in diameter, and also form part of the lower strap. Upon the cap is an iron hook; to this a chain is attached carrying the spring hook which bears the top shackle of the rods. The top of the bore-hole is surrounded by a wooden tube 1 ft. in diameter, and closed by a hinged valve, whose action is similar to that of a clack-valve; this has a hole in the centre for the rods to pass up and down freely. The valve permits of the introduction and withdrawal of the tools, and at the same time prevents anything from above falling into the bore-hole.

The lever is applied by pressure upon its outer end, and as the relation of the long to the short arm is as 4 to 1, a depression of 2 ft. in the one case produces an elevation of 6 in. in the other, the minimum range of action, the maximum being 26 in.

With the sheer-frame, the boring tools are worked in the same manner as in the preceding arrangements, Figs. 2387, 2388; but its portability, compactness, and adaptation of means to the required end render its use desirable wherever it is possible to obtain it.

When in the progress of the work it is found that the auger does not go down to the depth from which it was withdrawn after trial, tubing will generally be necessary. The hole should be enlarged from the surface, or, if not very deep, commenced afresh from the surface with a larger auger, and run down to nearly the same depth; the first length of tube is then driven into the hole, and when this is effected another tube, having similar dimensions to the first, is screwed into its upper end, and the driving repeated, and so on until a sufficient number of pipes have been used to reach to the bottom of the hole. If the ordinary auger is now introduced through these tubes, it will have free access to the clay or sand, and after a few feet deeper have been bored another pipe may be screwed on, and the whole driven further down. In this way from 10 to 20 ft. of soft stratum may be bored through. If the thickness of the surface clay or sand is considerable, the method here mentioned will not be effective, as the friction of the pipes caused by the pressure of the strata will be so great that perhaps not more than 80 or 100 feet can be driven without the pipes being injured. It will then be necessary to put down the first part of the bore-hole with a large auger, and drive in pipes of large diameter; the hole is continued of smaller diameter, and lined with smaller tubes projecting beyond the large tubes, as in Fig. 2389, until the necessity for their use ceases. It will be evident that to ensure success the tubing, whatever it is made of, should be as truly cylindrical as possible, straight, and flush surface, both outside and in. It will also be evident that in thus joining pieces of tubing together, the thickness ought to have a due proportion to the work required, and the force likely to be used in screwing or driving them down.

2387.



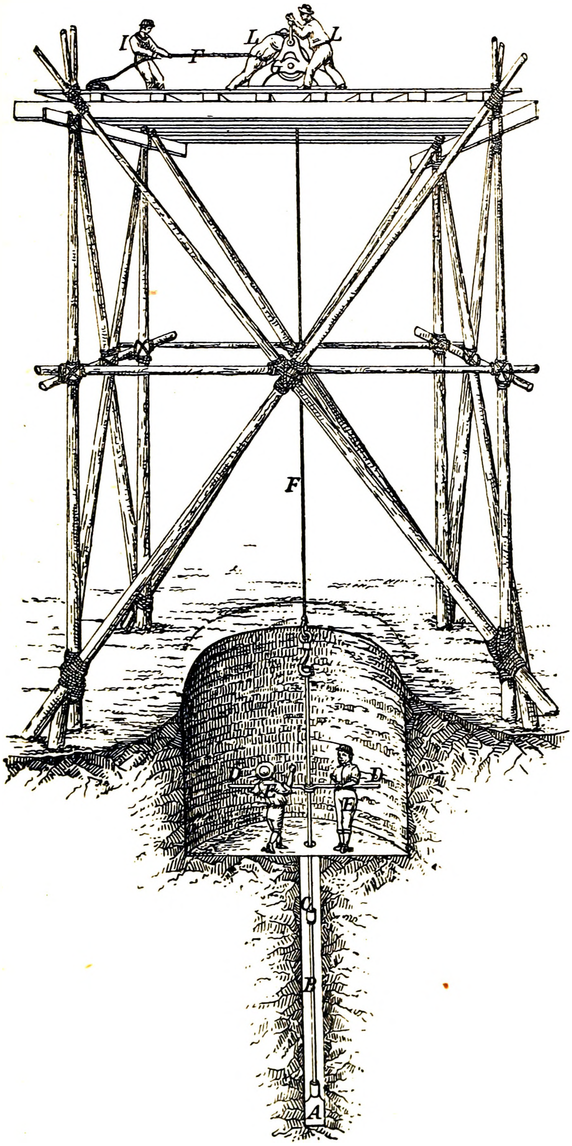
Wrought-iron tubes, when driven, must be worked carefully, by means of a ring made of wrought iron, from 1½ to 2 in. in height and ¾ in. thick, and of the form shown in Fig. 2390; or driven with a pipe-dolly such as that in Fig. 2384. The ring, or the dolly, is screwed into the lowermost boring rod, and worked at the same rate and in a similar manner to the chisel, due regard being had to the depth at which the driving is being done, as the weight of the boring rods will materially affect the strength of the blow delivered. Cast-iron tubing may be driven hard with a monkey. To withdraw broken or defective tubing quickly, two hooks attached to ropes are lowered down from opposite sides of the bore-hole, caught on the rim of the lowermost tube, and power applied to haul the tubing up bodily.

Figs. 2391 to 2395 show good methods of forming tube or pipe joints, both in cast and wrought iron, when not screwed.

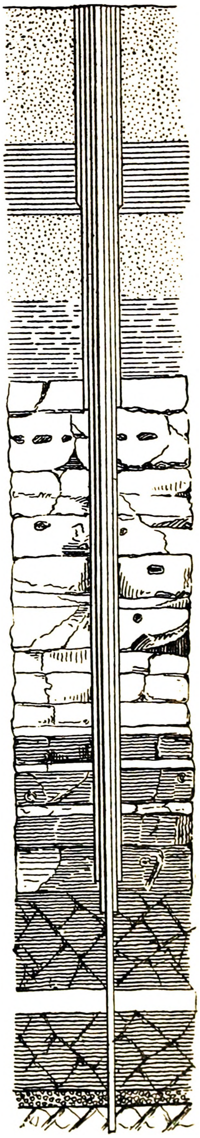
In some cases it is necessary to widen out holes below the sharp edge of tubing, so as to permit its descent. This is effected by a rimer, Fig. 2385, and is an operation requiring great care and attention.

To reduce the stoppages for the withdrawal of débris, the system of Fauvelle was introduced, but it is now very little practised on the Continent, and not at all in Great Britain. The principles upon which it was founded were; first, that the motion given to the tool in rotation was simply derived from the resistance that a rope would oppose to an effort of torsion; and therefore that the limits of application of the system were only such as would provide that the tool should be safely acted upon; and, secondly, that the injection of a current of water, descending through a central tube, should wash out the débris created by the cutting tool at the bottom. The difficulties attending the removal of the débris were great; and though the system of Fauvelle answered tolerably well when applied to shallow borings, it was found to be attended with such disadvantages when applied on a large scale, that it has been generally abandoned. The quantity of water required to keep the boring tool clear is a great objection to the introduction of this system, especially as in the majority of cases artesian wells are sunk in such places as are deprived of the advantage of a large supply.

2388.

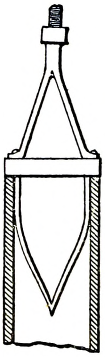


2389.

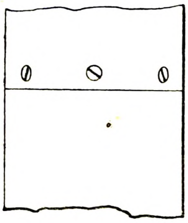


In the ordinary system of well boring, innumerable breakages and delays occur when a boring is required to be carried to any depth exceeding 200 or 300 ft., owing to the buckling of the rods, the crystallization of the iron by the constant jarring at each blow, and particularly the increased weight of the rods as the hole gets deeper. It follows from this that where the excavation is very deep, there is considerable difficulty in transmitting the blow of the tool, in consequence of the vibration produced in the long rod, or in consequence of the torsion; and, for the same reason, there is a danger of the blows not being equally delivered at the bottom. It has been attempted to obviate this difficulty, but without much success, by the use of hollow rods, presenting greater sectional area than was absolutely necessary for the particular case, in order to increase their lateral resistance to the blows tending to produce vibration.

2390.



2391.



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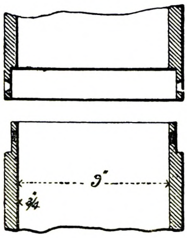
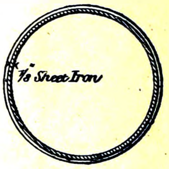
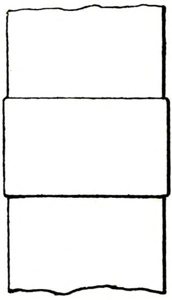
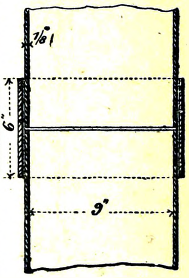


2393.





2394.



2395.

Mather and Platt's system has been already referred to at p. 526 of this Dictionary, and is shown in detail, Figs. 2396 to 2419.

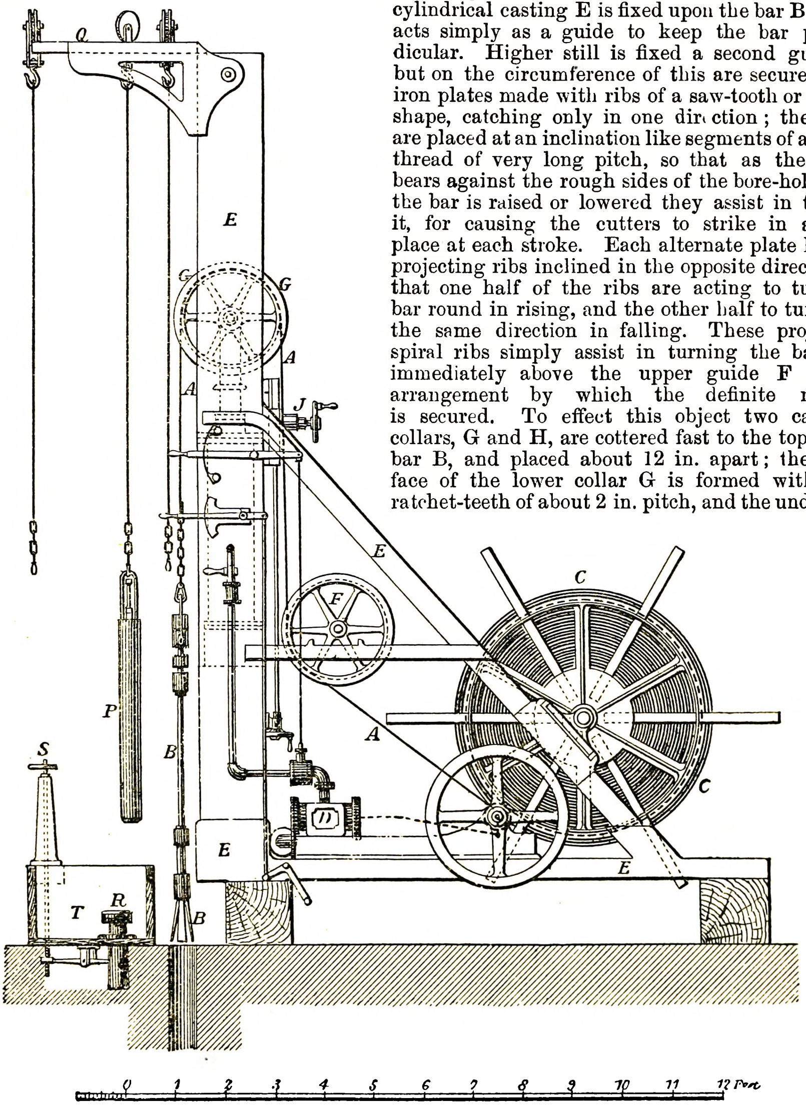
Figs. 2396 to 2402 are the mode of giving the percussive action to the boring tool, and the construction of the tool or boring-head, and of the shell-pump for clearing out the hole after the action of the boring-head. Instead of these implements being attached to rods, they are suspended by a flat hemp rope, about ½ in. thick and 4½ in. broad.

The flat rope A A, Fig. 2399, from which the boring-head B is suspended, is wound upon a large drum C driven by a steam-engine D with a reversing motion, so that one man can regulate the operation with the greatest ease. All the working parts are fitted into a wood or iron framing E E, rendering the whole a compact and complete machine. On leaving the drum C the rope passes under a guide pulley F, and then over a large pulley G carried in a fork at the top of the piston-rod of a vertical single-acting steam cylinder.

This cylinder, by which the percussive action of the boring-head is produced, is shown to a larger scale in the vertical sections, Figs. 2399, 2400; and in the larger size of machine here shown, the cylinder is fitted with a piston of 15 in. diameter, having a heavy cast-iron rod 7 in. square, which is made with a fork at the top carrying the flanged pulley G of about 3 ft. diameter, and of sufficient breadth for the flat rope A to pass over it. The boring-head having been lowered by the winding drum to the bottom of the bore-hole, the rope is fixed secure at that length by the clamp J; steam is then admitted underneath the piston in the cylinder H by the steam valve K, and the boring-tool is lifted by the ascent of the piston-rod and pulley G; and on arriving at the top of the stroke the exhaust valve L is opened for the steam to escape, allowing the piston-rod and carrying pulley to fall freely with the boring-tool, which falls with its full weight to the bottom of the bore-hole. The exhaust-port is 6 in. above the bottom of the cylinder, while the steam port is situated at the bottom; and there is thus always an elastic cushion of steam retained in the cylinder of that thickness for the piston to fall upon, preventing the piston from striking the bottom of the cylinder. The steam and exhaust valves are worked with a self-acting motion by the tappets M M, which are actuated by the movement of the piston-rod; and a rapid succession of blows is thus given by the boring tool on the bottom of the bore-hole. As it is necessary that motion should be given to the piston before the valves can be acted upon, a small jet of steam N is allowed to be constantly blowing into the bottom of the cylinder; this causes the piston to move slowly at first, so as to take up the slack of the rope and allow it to receive the weight of the boring-head gradually and without a jerk. An arm attached to the piston-rod then comes in contact with a tappet which opens the steam valve K, and the piston rises quickly to the top of the stroke; another tappet worked by the same arm then shuts off the steam, and the exhaust valve L is opened by a corresponding arrangement on the opposite side of the piston-rod, as in Fig. 2400. By shifting these tappets the length of stroke of the piston can be varied from 1 to 8 ft. in the large machine, according to the material to be bored through; and the height of fall of the boring head at the bottom of the bore-hole is double the length of stroke of the piston. The fall of the boring-head and piston can also be regulated by a weighted valve on the exhaust pipe, checking the escape of the steam, so as to cause the descent to take place slowly or quickly, as may be desired.

The boring-head B, Fig. 2396, is shown to a larger scale in Figs. 2401 to 2403, and consists of a wrought-iron bar about 4 in. diameter and 8 ft. long, to the bottom of which a cast-iron cylindrical block C is secured. This block has numerous square holes through it, into which the chisels or cutters D D are inserted with screwed taper shanks, as in Fig. 2402, so as to be very firm when working, but to be readily taken out for repairing and sharpening. Two different arrangements of the cutters are shown in the elevation, Fig. 2401, and the plan, Fig. 2403. A little above the block C another cylindrical casting E is fixed upon the bar B, which acts simply as a guide to keep the bar perpendicular. Higher still is fixed a second guide F, but on the circumference of this are secured cast-iron plates made with ribs of a saw-tooth or ratchet shape, catching only in one direction; these ribs are placed at an inclination like segments of a screw-thread of very long pitch, so that as the guide bears against the rough sides of the bore-hole when the bar is raised or lowered they assist in turning it, for causing the cutters to strike in a fresh place at each stroke. Each alternate plate has the projecting ribs inclined in the opposite direction, so that one half of the ribs are acting to turn the bar round in rising, and the other half to turn it in the same direction in falling. These projecting spiral ribs simply assist in turning the bar, and immediately above the upper guide F is the arrangement by which the definite rotation is secured. To effect this object two cast iron collars, G and H, are cottered fast to the top of the bar B, and placed about 12 in. apart; the upper face of the lower collar G is formed with deep ratchet-teeth of about 2 in. pitch, and the under face of the top collar H is formed with similar ratchet-teeth, set exactly in line with those on the lower collar. Between these collars and sliding freely on the neck of the boring bar B is a deep bush J, which is also formed with corresponding ratchet-teeth on both its upper and lower faces; but the teeth on the upper face are set half a tooth in advance of those on the lower face, so that the perpendicular side of each tooth on the upper face of the bush is directly above the centre of the inclined side of a tooth on the lower face. To this bush is attached the wrought-iron bow K, by which the whole boring bar is suspended with a hook and shackle O, Fig. 2399, from the end of the flat rope A. The rotary motion of the bar is obtained as follows: when the boring tool falls and strikes the blow, the lifting-bush J, which during the lifting has been engaged with the ratchet-teeth of the top collar H, falls upon those of the bottom collar G, and thereby receives a twist backwards through the space of half a tooth; and on commencing to lift again, the bush rising up against the ratchet-teeth of the top collar H, receives a further twist backwards through half a tooth. The flat rope is thus twisted backwards to the extent of one tooth of the ratchet; and during the lifting of the tool it untwists itself again, thereby rotating the boring tool forwards through that extent of twist between each successive blow of the tool. The amount of

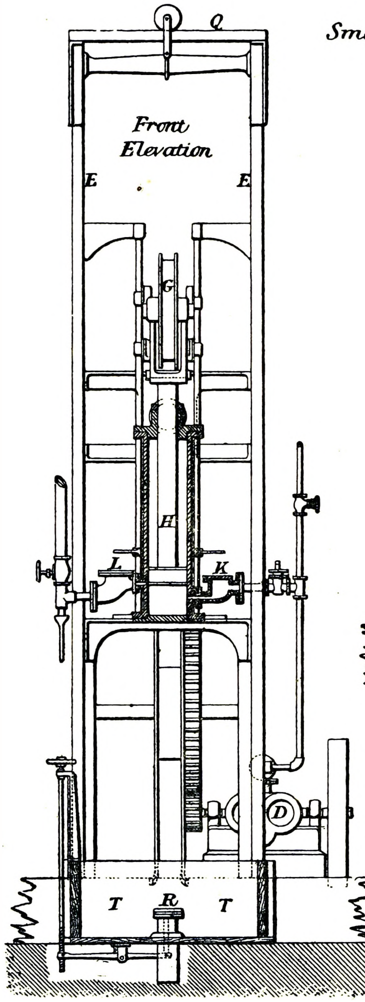
2396.



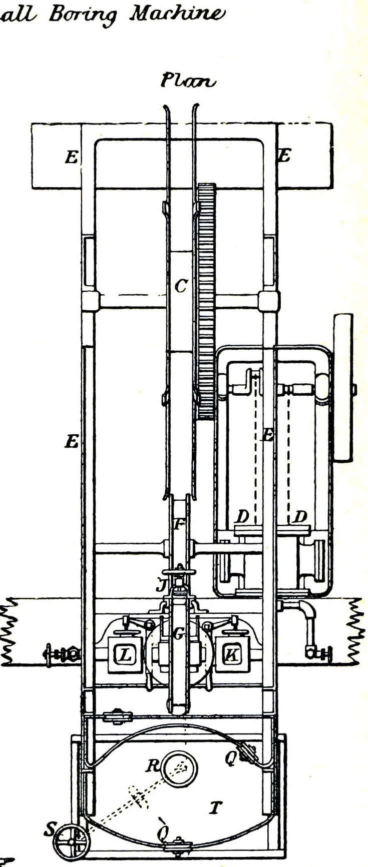
the rotation may be varied by making the ratchet-teeth of coarser or finer pitch. The motion is entirely self-acting, and the rotary movement of the boring tool is ensured with mechanical accuracy. This simple and most effective action taking place at every blow of the tool produces a constant change in the position of the cutters, thus increasing their effect in breaking the rock.

The shell-pump, for raising the material broken up by the boring-head, is shown in Figs. 2404, 2405, and consists of a cylindrical shell or barrel P of cast iron, about 8 feet long and a little smaller in diameter than the size of the bore-hole. At the bottom is a clack A opening upwards, somewhat similar to that in ordinary pumps; but its seating, instead of being fastened to the cylinder P, is in an annular frame C, which is held up against the bottom of the cylinder by a rod D passing up to a wrought-iron bridge E at the top, where it is secured by a cotter F. Inside the cylinder works a bucket B, similar to that of a common lift-pump, having an indiarubber disc valve on the top side; and the rod D of the bottom clack passes freely through the bucket. The rod G of the bucket itself is formed like a long link in a chain, and by this link the pump is suspended from the shackle O, Fig. 2399 at the end of the flat rope, the bridge E, Fig. 2404, preventing the bucket from being drawn out of the cylinder. The bottom clack A is made with an indiarubber disc, which opens sufficiently to allow the water and smaller particles of stone to enter the cylinder; and in order to enable the pieces of broken rock to be brought up as large as possible, the entire clack is free to rise bodily about 6 inches from the annular frame C, as shown in Fig. 2404, thereby affording ample space for large pieces of rock to enter the cylinder, when drawn in by the up stroke of the bucket.

2397.

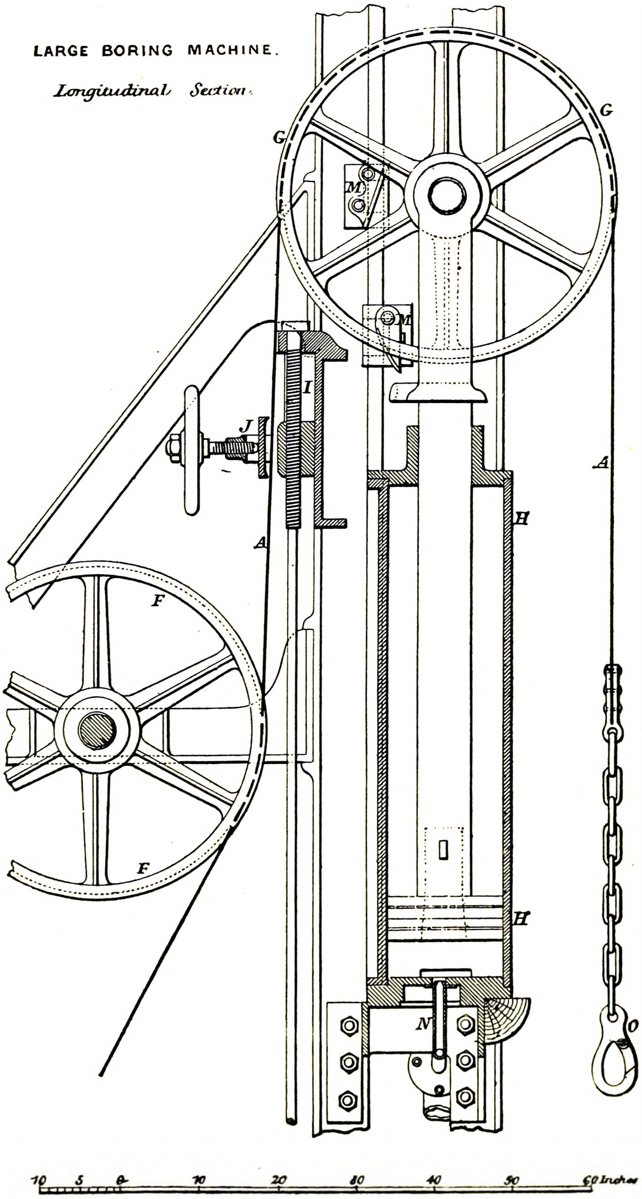


2398.



The general working of the boring machine is as follows: The winding drum C, Fig. 2396, is 10 feet diameter in the large machine, and is capable of holding 3000 feet length of rope $4\frac{1}{2}$ inches broad and $\frac{1}{2}$ inch thick. When the boring-head B is hooked on the shackle at the end of the rope A, its weight pulls round the drum and winding engine, and by means of a break it is lowered steadily to the bottom of the bore-hole; the rope is then secured at that length by screwing up tight the clamp J. The small steam jet N, Figs. 2399, 2400, is next turned on, for starting the working of the percussion cylinder H; and the boring-head is then kept continuously at work until it has broken up a sufficient quantity of material at the bottom of the bore-hole. The clamp J which grips the rope is made with a slide and screw I, Fig. 2399, whereby more rope can be gradually given out as the boring-head penetrates deeper in the hole. In order to increase the lift of the boring-head, or to compensate for the elastic stretching of the rope, which is found to amount to 1 inch in each 100 feet length, it is simply necessary to raise the top pair of tappets on the tappet rods whilst the percussive motion is in operation. When the boring-head has been kept

2399.

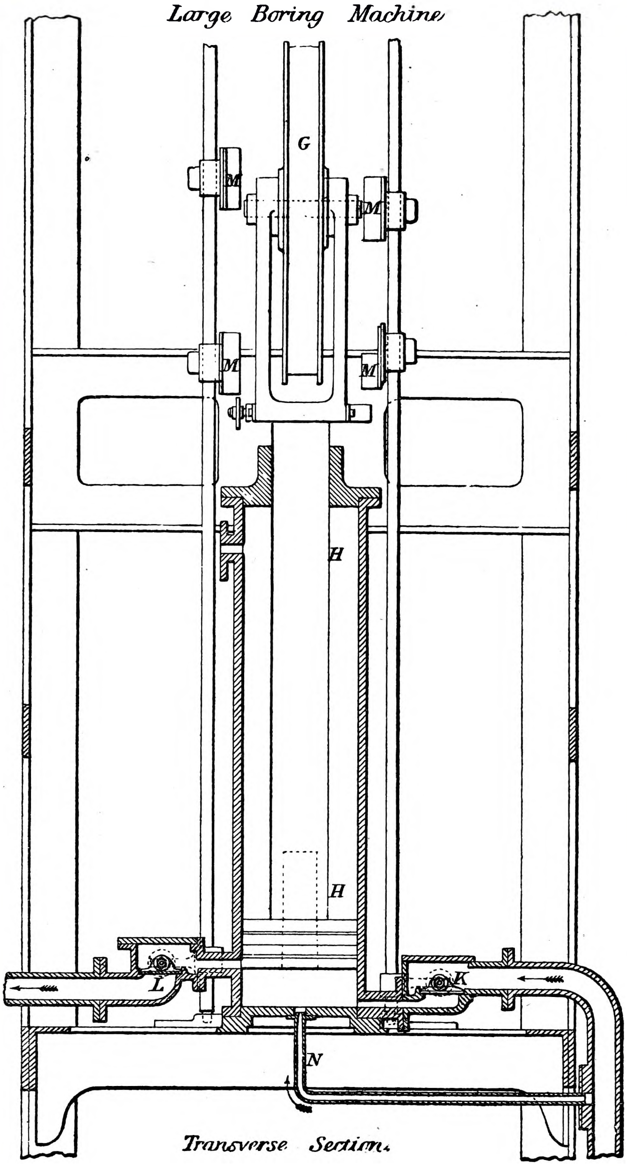


at work long enough, the steam is shut off from the percussion cylinder, the rope unclamped, the winding engine put in motion, and the boring head wound up to the surface, where it is then slung from an overhead suspension bar Q, Fig. 2396, by means of a hook mounted on a roller for running the boring head away to one side, clear of the bore-hole.

The shell-pump is next lowered down the bore-hole by the rope, and the débris pumped into it by lowering and raising the bucket about three times at the bottom of the hole, which is readily effected by means of the reversing motion of the winding engine. The pump is then brought up to the surface, and emptied by the following very simple arrangement: It is slung by a traversing hook from the overhead suspension bar Q, Fig. 2396, and is brought perpendicularly over a small table R in the waste tank T; and the table is raised by the screw S until it receives the weight of the pump. The cotter F, Fig. 2404, which holds up the clack seating C at the bottom of the pump, is then knocked out; and the table being lowered by the screw, the whole clack seating C descends with it, as shown in Fig. 2405, and the contents of the pump are washed out by the rush of water contained in the pump cylinder. The table is then raised again by the screw, replacing the clack seating in its proper position, in which it is secured by driving the cotter F into the slot at the top; and the pump is again ready to be lowered down the bore-hole as before. It is sometimes necessary for the pump to be emptied and lowered three or four times in order to remove all the material that has been broken up by the boring-head at one operation.

2400.

Large Boring Machine

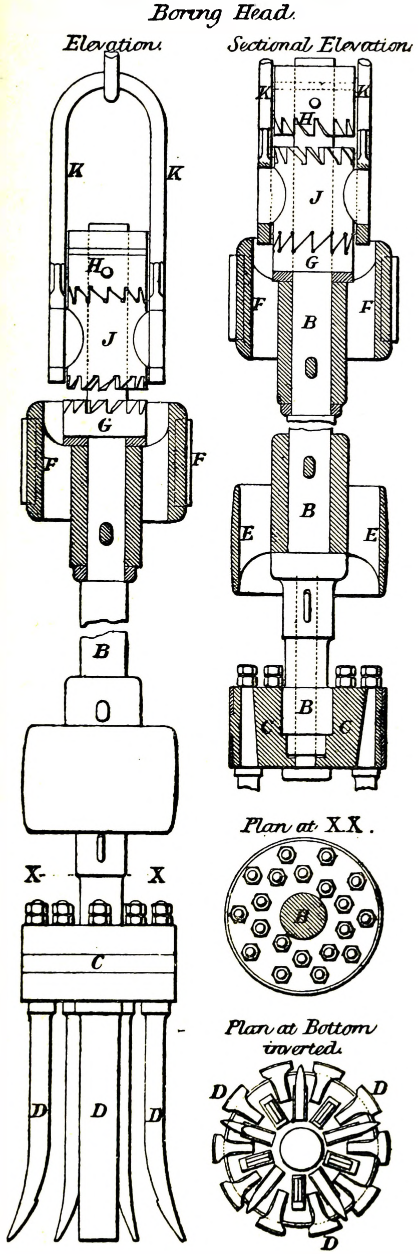


Transverse Section.

The rapidity with which these operations may be carried on is found in the experience of the working of the machine to be as follows; The boring-head is lowered at the rate of 500 feet a minute. The percussive motion gives twenty-four blows a minute; this rate of working continued for about ten minutes in red sandstone and similar strata is sufficient for enabling the cutters to penetrate about 6 inches depth, when the boring-head is wound up again at the rate of 300 feet a minute. The shell-pump is lowered and raised at the same speeds, but only remains down about two minutes; and the emptying of the pump when drawn up occupies about two or three minutes.

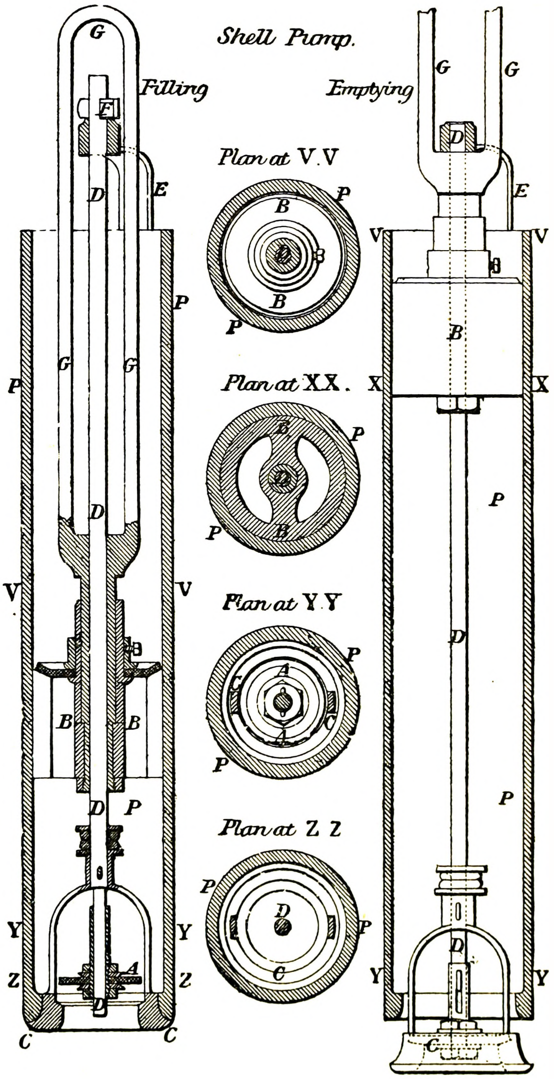
In the construction of this machine it will be seen that the great desideratum of all earth boring has been well kept in view; namely to bore holes of large diameter to great depths with rapidity and safety. The object is to keep either the boring-head or the shell-pump constantly at work at the bottom of the bore-hole, where the actual work has to be done; to lose as little time as possible in raising, lowering, and changing the tools; to expedite all the operations at the surface; and to economise manual labour in every particular. With this machine, one man standing on a platform at the side of the percussion cylinder performs all the operations of raising and lowering by the winding engine, changing the boring-head and shell-pump, regulating the percussive action, and clamping or unclamping the rope: all the handles for the various steam valves are close to his hand, and the break for lowering is worked by his foot. Two labourers attend to changing the cutters and clearing the pump. Duplicate boring-heads and pumps are slung to the overhead suspension bar Q, Fig. 2396, ready for use, thus avoiding all delay when any change is requisite.

2401. 2402.


Boring Head.
Elevation.
Sectional Elevation.
K
H
J
G
F
E
B
C
D
X
Plan at XX.
Plan at Bottom inverted.

2403.

2405.

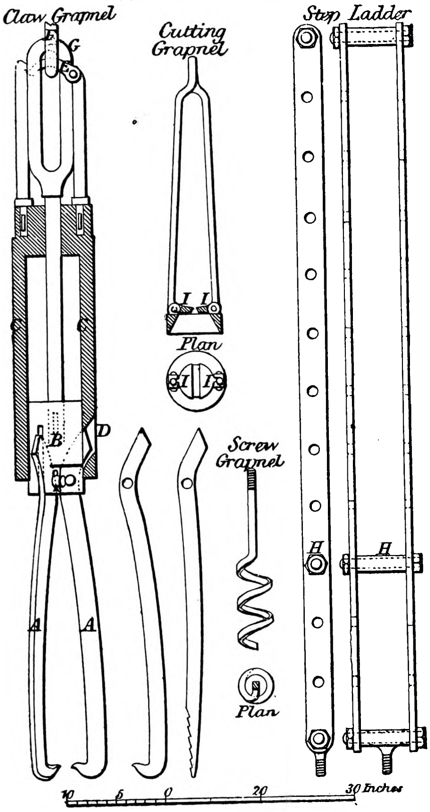

Shell Pump.
Filling
Emptying
G
F
D
E
P
V
B
Y
Z
C
A
Plan at V.V
Plan at XX.
Plan at Y.Y
Plan at Z Z
X

As is well known by those who have charge of such operations, in well boring innumerable accidents and stoppages occur from causes which cannot be prevented, with however much vigilance and skill the operations may be conducted. Hard and soft strata intermingled, highly inclined rocks, running sands, and fissures and dislocations are fruitful sources of annoyance and delay, and sometimes of complete failure; and it will therefore be interesting to notice a few of the ordinary difficulties arising out of these circumstances. In all the bore-holes yet executed by this system, the various special instruments used under any circumstances of accident or complicated strata are fully shown in Figs. 2406 to 2412.

The boring-head while at work may suddenly be jammed fast, either by breaking into a fissure, or in consequence of broken rock falling upon it from loose strata above. All the strain possible is then put upon the rope, either by the percussion cylinder or by the winding engine; and if the rope is an old one or rotten it breaks, leaving perhaps a long length in the hole. The claw grapnel, Fig. 2406, is then attached to the rope remaining on the winding drum, and is lowered until it rests upon the slack broken rope in the bore-hole. The grapnel is made with three claws A A centred in a cylindrical block B, which slides vertically within the casing C, the tail ends of the claws fitting into inclined slots D in the casing. During the lowering of the grapnel, the claws are kept open in consequence of the trigger E being held up in the position shown in Fig. 2406, by the long link F, which suspends the grapnel from the top rope. But as soon as the grapnel rests upon the broken rope below, the suspending link F continuing to descend allows the trigger E to fall out of it; and then in hauling up again, the grapnel is lifted only by the bow G of the internal block B, and the entire weight of the external casing C bears upon the inclined tail-ends of the claws A, causing them to close in tight upon the broken rope and lay hold of it securely. The claws are made either hooked at the extremity or serrated. The grapnel is then hauled up sufficiently to pull the broken rope tight, and wrought-iron rods 1 inch square with hooks attached at the bottom are let down to catch the bow of the boring-head, which is readily accomplished. Two powerful screw-jacks are applied to the rods at the surface, by means of the step-ladder shown in Fig. 2409, in which the cross-pin H is inserted at any pair of the holes, so as to suit the height of the screw-jacks.

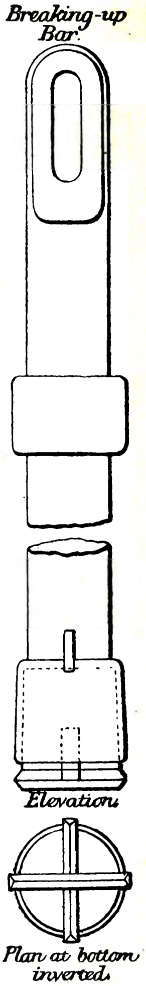
2406. 2407. 2409.

ACCIDENT TOOLS



2408.

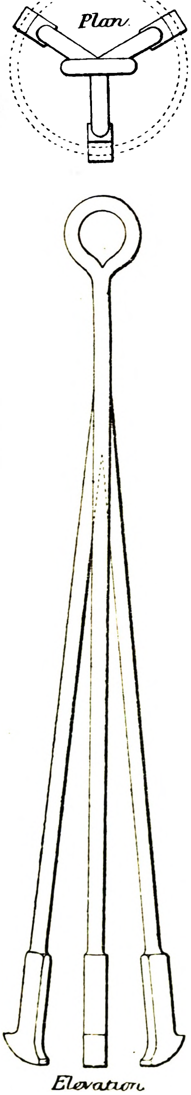
2410.



If the boring-head does not yield quickly to these efforts, the attempt to recover it is abandoned, and it is got out of the way by being broken up into pieces. For this purpose the broken rope in the bore-hole has first to be removed, and it is therefore caught hold of with a sharp hook and pulled tight in the hole, while the cutting grapnel, shown in Fig. 2407, is slipped over it and lowered by the rods to the bottom. This tool is made with a pair of sharp cutting jaws or knives I I opening upwards, which in lowering pass down freely over the rope; but when the rods are pulled up with considerable force, the jaws nipping the rope between them cut it through, and it is thus removed altogether from the bore hole. The solid wrought-iron breaking-up bar, Fig. 2410, which weighs about a ton, is then lowered, and by means of the percussion

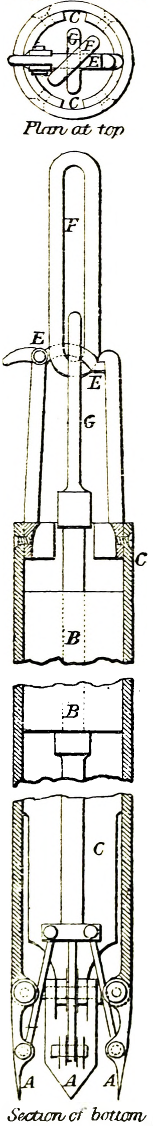
2411.

Grapnel for Tubes.



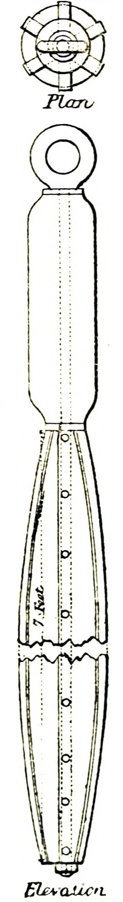
2412.

Grapnel for Cores



2413.

Straightening Plug for Tubes



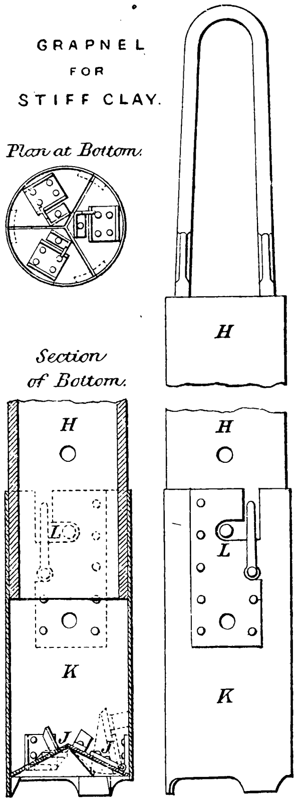
cylinder it is made to pound away at the boring-head, until the latter is either driven out of the way into one side of the bore-hole, or broken up into such fragments as that, partly by the shell-pump and partly by the grapnels, the whole obstacle is removed. The boring is then proceeded with again, the same as before the accident.

The same mishap may occur with the shell-pump getting jammed fast in the bore-hole, as illustrated in Fig. 2416; and the same means of removing the obstacle are then adopted. Experience has shown the danger of putting any greater strain upon the rope than the percussion cylinder can exert; and it is therefore usual to lower the grapnel rods at once, if the boring-head or pump gets fast, thus avoiding the risk of breaking the rope.

The breaking of a cutter in the boring-head is not an uncommon occurrence. If, however, the bucket grapnel, or the small screw grapnel, Fig. 2408, be employed for its recovery, the hole is readily cleared without any important delay. The screw grapnel, Fig. 2408, is applied by means of the iron grappling rods, so that by turning the rods the screw works itself round the cutter or other similar article in the bore-hole, and securely holds it while the rods are drawn up again to the surface. The bucket grapnel, Fig. 2412, is also employed for raising clay, as well as for the purpose of bringing up cores out of the bore-hole, where these are not raised by the boring-head itself in the manner already described. The action of this grapnel is nearly similar to that of the claw grapnel, Fig. 2406; the three jaws, A A, hinged to the bottom of the cylindrical casing C, and attached by connecting rods to the internal block B, sliding within the casing C, are kept open during the lowering of the tool, the trigger E being held up in the position, Fig. 2412, by the long suspending link F. On reaching the bottom, the trigger is liberated by the further descent of the link F, which, in hauling up again, lifts only the bow G of the internal block B; so that the jaws A are made to close inwards upon the core, which is thus grasped firmly between them and brought up within the grapnel. Where there is clay or similar material at the bottom of the bore-hole, the weight of the heavy block B in the grapnel causes the sharp edges of the pointed jaws to penetrate to some depth into the material, a quantity of which is thus enclosed within them and brought up.

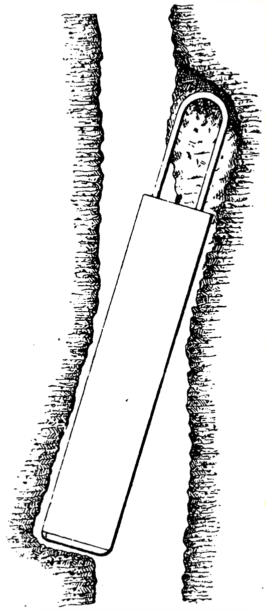
Another grapnel is also used where a bore-hole passes through a bed of very stiff clay, as in Figs. 2414, 2415, and consists of a long cast-iron cylinder H fitted with a sheet-iron mouthpiece K at the bottom, in which are hinged three conical steel jaws J J opening upwards. The weight of the tool forces it down into the clay with the jaws open; and then on raising it the jaws, having a tendency to fall, cut into the clay and enclose a quantity of it inside the mouthpiece, which on being brought up to the surface is detached from the cylinder H and cleaned out. A second mouthpiece is put on and sent down for working in the bore-hole while the first is being emptied, the attachment of the mouthpiece to the cylinder being made by a common bayonet-joint L, so as to admit of readily connecting and disconnecting it.

2414. 2415.



GRAPNEL FOR STIFF CLAY.

2416.

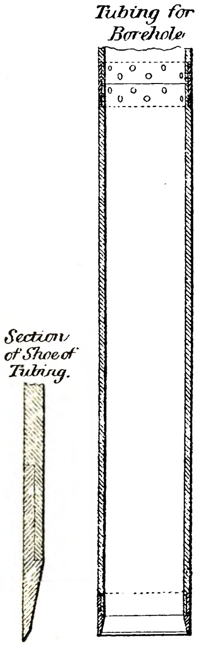


Shell Pump Jammed in Borehole.

A running sand in soft clay is, however, the most serious difficulty met with in well boring. Under such circumstances the bore-hole has to be tubed from top to bottom, which greatly increases the expense of the undertaking, not only by the cost of the tubes, but also by the time and labour expended in inserting them. When a permanent water supply is the main object of the boring, the additional expense of tubing the bore-hole is not of much consequence, as the tubed hole is more durable, and the surface water is thereby excluded; but in exploring for mineral it is a serious matter, as the final result of the bore-hole is then by no means certain. The mode of inserting tubes has become a question of great importance in connection with this system of boring, and much time and thought having been spent in perfecting the method now adopted, its value has been proved by the repeated success with which it has been carried out.

The tubes used by Mather and Platt are of cast iron, varying in thickness from $\frac{5}{8}$ to 1 in. according to their diameter, and are all 9 ft. in length. The successive lengths are connected together by means of wrought-iron covering hoops 9 in. long, made of the same outside diameter as the tube, so as to be flush with it. These hoops are from $\frac{1}{4}$ to $\frac{3}{8}$ in. thick, and the ends of each tube are reduced in diameter by turning down for $4\frac{1}{2}$ in. from the end, to fit inside the hoops, Fig. 2417. A hoop is shrunk fast on one end of each tube, leaving $4\frac{1}{2}$ in. of socket projecting to receive the end of the next tube to be connected. Four or six rows of screws with countersunk heads, placed at equal distances round the hoop, are screwed through into the tubes to couple the two lengths securely together. Thus a flush joint is obtained both inside and outside the tubes. The lowest tube is provided at the bottom with a steel shoe, having a sharp edge for penetrating the ground more readily.

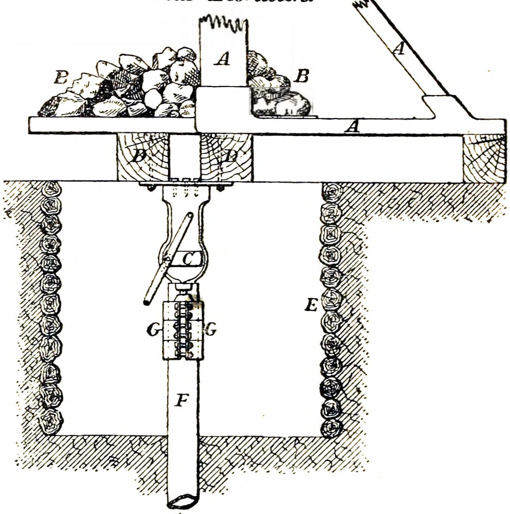
2417.



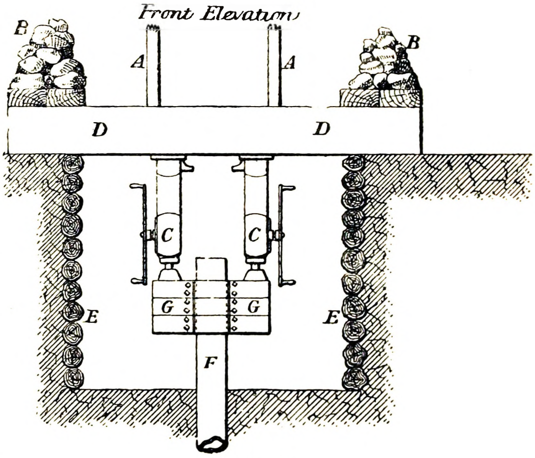
2418.

Tube-Forcing Apparatus with Screwjacks.

Side Elevation.



Front Elevation.



2419.

In small borings, from 6 to 12 in. diameter, the tubes are inserted into the bore-hole by means of screw-jacks, by the simple and inexpensive method shown in Figs 2418, 2419. The boring machine foundation A A, which is of timber, is weighted at B B by stones, pig iron, or any available material; and two screw-jacks C C, each of about 10 tons power, are secured with the screws downwards, underneath the beams D D crossing the shallow well E, which is always excavated at the top of the bore-hole. A tube F having been lowered into the mouth of the bore-hole by the winding engine, a pair of deep clamps G are screwed tightly round it, and the screw-jacks acting upon these clamps force the tube down into the ground. The boring is then resumed, and as it proceeds the jacks are occasionally worked, so as to force the tube if possible even ahead of the boring tool. The clamps are then slackened and shifted up the tubes, to suit the length of the screws of the jacks; two men work the jacks, and couple the lengths of tubes as they are successively added. The actual boring is carried on simultaneously within the tubes, and is not in the least impeded by their insertion, which simply involves the labour of an additional man or two.

A more perfect and powerful tube-forcing apparatus is adopted where tubes of from 18 to 24 in. diameter have to be inserted to a great depth.

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